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"The mobile phone, the Net, and the spread of information—a deadly combination for dictators"

Q+A, p22

BIG DATA WILL SAVE POLITICS

BONO: DATA CAN FIGHT POVERTY AND CORRUPTION

SASHA ISSENBERG: DATA MAKES ELECTIONS SMARTER

JOE TRIPPI: DATA PUTS THE SOUL BACK INTO POLITICS

PLUS: OUR LETTER TO PRESIDENT OBAMA


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From the Editor

"Few events in American life other than a presidential election touch 126 million adults, or even a significant fraction that many, on a single day," writes Sasha Issenberg in "A More Perfect Union" (p. 38), the definitive explanation of the part technology played in the 2012 election. Americans care about elections because, in the absence of much opportunity for direct democracy, they are how citizens participate in the representative government of the republic.

But the electoral techniques of both parties have tended to diminish the active participation of citizens. Joe Trippi, a longtime Democratic political operative, writes about his unhappy experiences in a prologue to Issenberg's narrative (see it on p. 34). In the last weeks of California's 1982 gubernatorial election, pollsters told the campaign of Mayor Tom Bradley, the Democratic candidate, to divert $2 million from get-out-the-vote operations to television advertising. Bradley lost. "Decisions like this were made in campaign after campaign, within both parties, for the next 30 years," Trippi says. "Television won every time. Poll-driven television ads sucked the heart and soul out of politics without much challenge."

Yet, Trippi writes, "during the very years that politics stagnated, technology evolved to allow people to share ideas and stories or sell and buy things from each other in ways that really improved their lives." The application of Internet technologies during the 2004 and 2008 elections, and the use of data analytics and experimental methods from the social sciences in the 2012 election, have transformed the way campaigns mobilize their supporters and sway the persuadable. In the future, these techniques will change how administrations govern.

In Issenberg's account, the combination of analytics and experimentation won President Barack Obama reëlection. He writes that the techniques "enabled a presidential candidate to view the electorate the way local candidates do: as a collection of people … each of them approachable on his or her own terms, their changing levels of support and enthusiasm open to measurement and, thus, to respect." Obama 2012 was a community organizer's local ward campaign played on a national stage. Romney 2012, by contrast, never had the resources or, finally, the understanding to run such a campaign. Trippi quotes a dejected Republican campaign staffer: "We weren't even running in the same race."

Trippi and Issenberg see the new methods mostly as forces for good. But another, less Panglossian opinion suggests itself. Both campaigns (but especially the president's) spoke with admirable efficiency and unfaltering discipline to some people: those in electorally important states who had voted for their party's candidate in the last election, or who could be moved to vote for their party's candidate in this election, or who could be lured from their natural party to vote for the other party's candidate. Neither candidate spoke to the whole nation, despite the periodic insistence of both that the 2012 presidential election constituted a clear "choice." The election was not noted for any great debate about the future of the country, despite the tremendous challenges the new administration will face (see our letter to the president, p. 50). Throughout, I felt sure the Founders, who abhorred party "faction," would have been shocked—not by the wizardry of our technologies but, rather, by the smallness of our concerns and the dishonesty of our arguments.

But write to me at jason.pontin@technologyreview.com and tell me what you think.

MARK OSTOW

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Contents

Front

JANUARY/FEBRUARY 2013

Back

ON THE COVER:
Bono photographed by Peter Hapak

ABOVE: PHOTOGRAPH BY CHRIS LAKE

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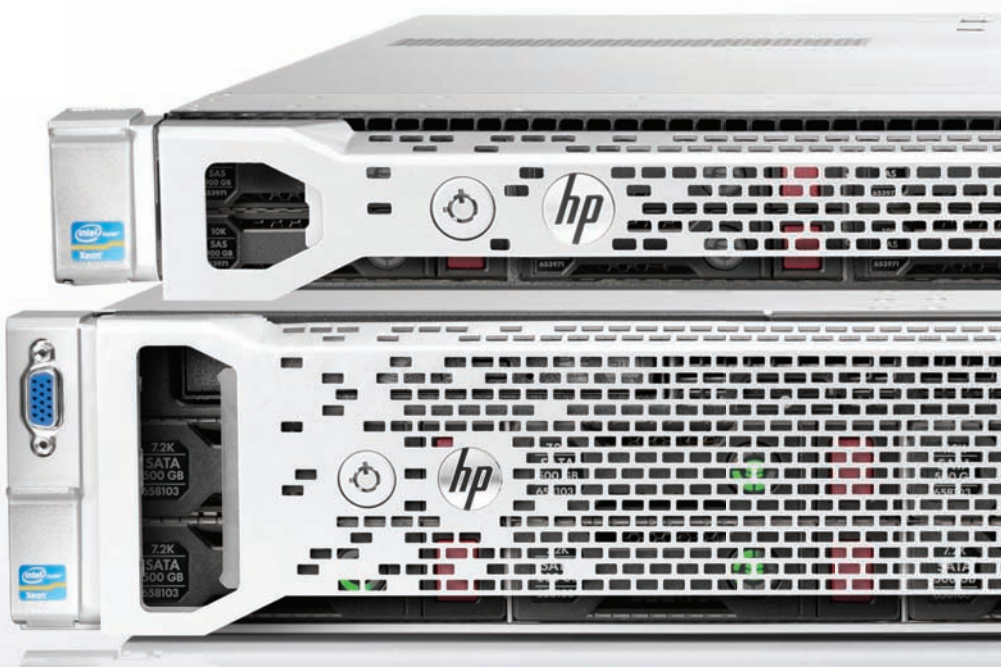

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De Technologia non multum scimus. Scimus autem, quid nobis placeat.

the ultimate infrastructure for your business

OVH.com, the number 1 in hosting providing in Europe*, is releasing its Cloud Computing offers in North America through its data center based in Canada.

**Netcraft, November 2012*

It was founded by Octave Klaba in 1999, and has grown tremendously since then, becoming Europe's leading company for hosting providing. Boasting 500 employees, 140 000 servers hosted in its 11 data centers, OVH.com is now present across 3 continents with its 16 subsidiaries, and is now the international reference for all who demand the best of Internet.

PHOTO: OVH.COM

Reducing Costs While Massively Investing in Innovation

OVH.com owes its success to a very simple idea : to do things differently. The company designs and builds its own data centers, constructs its servers on its own assembly lines, manages its own worlwide network and offers technical support with its own teams. Beyond this mastery of the product lifecycle management, OVH.com is about constant innovation. It is perpetually researching and developing the technologies that would augment and optimize the performances of its products.

To reduce the energy-related costs of its data centers, OVH.com has developed a water cooling system for its servers, which has led to the removal of all air conditioning and to a current PUE of 1.1 to 1.2. This cost reduction affects customers directly : since production expenses are lower, prices paid by clients also are.

The assembly lines in the data centers make it possible to build the servers in less than an hour. Such industrialization lets the hosting provider achieve substantial economies of scale, and guarantees mastery over the design of its servers. Each component for each machine is carefully selected as to build hardware architecture of an unequaled sturdiness and reliability.

Inventing the Future in Hosting Providing

Being a major player in Cloud Computing, OVH.com equipped itself with strong virtualization infrastractures in 2010. As of today, OVH.com has received the vCloud Service Provider of the Year trophy for the EMEA zone as well as the vCloud Datacenter Services Provider award from VMware.

The quality of OVH.com's network is an undeniable advantage : it is entirely redundant, with a capacity of 2Tbps, stretching across Europe, North America and Asia via 33 peering points. This is a major asset to ensure optimal access to virtual resources.

OVH.com's Cloud Computing offers enhanced versions of VMware's solutions. These tools have been tested and proven, and immensely simplify virtual environments. OVH.com is one of the few companies to optimize the creation, management and maintenance features of its Cloud while offering 24/7 technical support.

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Feedback

A PROMISING START

THE REIMAGINED, REVAMPED PRINT VERsion of *MIT Technology Review*, with its provocative Buzz Aldrin cover, inspired (mostly) positive reader reaction. Among those who wrote in to offer kudos was **Rasiklal P. Shah**, of Latham, New York: "I've been reading *Technology Review* since 1967, but the latest issue is amazing. I couldn't put it down until I'd read it cover to cover. All of the goals of your redesign have paid off in amazing ways."

Brad Peters of Costa Mesa, California, felt likewise: "That zinger on the cover—that's got to be the best cover I've seen, on any magazine, in half a century."

Reiner Decher of Seattle, on the other hand, says he's seen, in our very pages, the same glorification of the trivial that we're now bemoaning. He says he'd like to see the magazine help figure out how we move forward in the wake of disasters like Hurricane Sandy. "Instead, I see Buzz Aldrin asking mind-blowingly superficial questions. In a previous issue, I see articles about the most promising scientists under the age of 35. Where is the social benefit in that?"

THE TROUBLE WITH PROBLEMS

EDITOR IN CHIEF JASON PONTIN SUMMED up the issue with his essay "Why We Can't Solve Big Problems," in which he looked into why our society used to find it so much easier to tackle what seemed like intractable difficulties. **Darrell Briggs** of Chelmsford, Massachusetts, argued that the problem is more fundamental—we're so reliant on machines that we no longer trust our own brains: "The Apollo onboard computer had the horsepower of an Atari game. If you asked any engineer who graduated in the last 20 years if he or she could put a man on the moon using only that equipment, they'd look at you like you were crazy. Back in the '90s I was trying to solve problems with test probes used on semiconductor wafers. I went to a young mechanical engineer and outlined the problem. He told me it would take three months to build a model and test the idea. I told him to throw away the computer on his desk and use the one on his shoulders. That afternoon he came to me with a look of wonder on his face. He'd had an epiphany: he could solve a real problem using only pencil and paper and what he was taught in some Engineering 101 course."

LEAVE MARS TO THE MARTIANS

IN "THE DEFERRED DREAMS OF MARS," deputy editor Brian Bergstein wrote about a pocket within NASA where aspirations of a manned mission to the Red Planet live on. **Robert J. Yaes** of Gaithersburg, Maryland, responded: let's just give up, already. "I am amazed that 40 years after the last Apollo mission we are still unable to admit that human space exploration is a dead-end technology. It has no future because, while we can design devices to function in any extraterrestrial environment, human beings were 'designed,' by three billion years of natural selection, to survive only in the narrow range of conditions found at the surface of the Earth. Thus for every pound of human we send into space, we have to send a ton of equipment to maintain life. So while a return to the moon is feasible, a similar trip to Mars may be impossible even if we devote our entire gross national product to the project."

Stanley D. Young of Fort Collins, Colorado, wrote: "I'm a baby boomer who was caught up in the excitement of the moon program, but it doesn't stand up to critical examination now. We're stuck here on our globe. It can be a wonderful Eden as long as we don't screw it up too much."

Howard Hendrix of Shaver Lake, California, on the other hand, felt the Mars effort has an appeal that transcends logic. "As astronaut Stan Love says, 'We like it, as people, when people do things. If all you're after is science data—sure, send robots. But we as human beings feel an attachment when humans go and do things like this.' To those who are keeping the flame of human Mars exploration alive, I can only say: Shine on, you crazy diamonds."

BEWARE OF THE PROFBOTS

HENDRIX HAD A SIMILARLY PRO-HUMAN reaction to Nicholas Carr's feature "The Crisis in Higher Education" and its take on the rise of massive open online courses: "The story makes clear that the current crop of educational corporations are more about stimulating the development of artificial intelligence through the manipulation of massive data sets than about stimulating the development of human intelligence. I'll take the redundancies of flawed, old-school humans over the shiny new profbots anytime." T

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Views

Yasheng Huang

Mark Brownstein

Samuel Sia

ECONOMICS

China's Challenge

If China wants an innovation-based economy, it will need to make political and institutional changes, says Yasheng Huang.

Since 1978, the Chinese economy has seen phenomenal growth. Whether it can be maintained is unclear. The country's export growth is decelerating quickly, and China already annually invests an amount equivalent to about half its GDP in assets and infrastructure—probably a higher proportion than any other country in peacetime. Now that China has completed its once-in-a-decade leadership transition, its leaders should be preparing to replace the rapid-growth model of the last three decades with one that requires less investment and is less reliant on cheap labor to provide a competitive advantage.

In 1994, China could drive growth by copying technology from other countries. Political features such as the rule of law, intellectual-property rights, labor rights, and democracy were less important, even a hindrance. But as a country gets richer, innovation, productivity, and domestic entrepreneurs become more important. The problem is not that China doesn't value science and technology. There is no shortage of expertise—many Chinese leaders are trained engineers, and the country invests roughly 2 percent of its huge economy in R&D, a level attained by only a few fairly rich countries. But research shows that these massive investments have had far less impact than one would expect.

One reason has to do with the environment in which Chinese research takes place. Universities in China are tightly controlled by the Ministry of Education. In comparison to their fiercely independent counterparts in the West, Chinese professors are like company employees. Research projects are often directed from the top down rather than being initiated by professors and researchers. The dissemination of research findings often has to take a back seat to the political need to maintain "stability."

Chinese leaders want economic growth to come from innovations based on technology and science—a laudable goal. But it can't be achieved by simply adding a massive dose of R&D spending to China's current growth model. Technology-based growth requires protection for intellectual property, freedom to think and challenge authority, and a government with limited reach and power. In other words, it requires Western institutions.

As the second-largest economy in the world, China needs to prepare for this institutional transition. It will require vision, political courage, and more than a tweaking of the existing system. Does the new leadership have what it takes to move the country in that direction?

Yasheng Huang is the international program professor in Chinese economy and business at MIT's Sloan School of Management and author of Capitalism with Chinese Characteristics.

ENVIRONMENT

Safer Fracking

Strong regulations and improved public disclosure are needed, says Mark Brownstein.

Can hydrofracking—using fluids to break open underground rock formations and recover trapped natural gas—be done safely? This is a question I am often asked by friends who read

ANDY FRIEDMAN

stories linking shale gas production to incidents of water pollution. While fracking is frequently blamed for contaminating groundwater, studies indicate that pollution may actually stem from more basic issues like faulty well construction and design or improper wastewater disposal.

No matter the cause of the pollution, people should not be forced to trade their children's health or quality of life for cheap energy. Serious questions about the environmental and public-health impact of natural-gas drilling need to be addressed (see "Drilling for Shale Gas," p. 26).

While the burden of proof is on industry and regulators to show that shale gas development can be done without polluting the water and air or damaging our climate, one needs to be clear-eyed on the issue. Like any industrial activity, natural-gas development has risks, which can be reduced in a variety of ways. But with thousands of gas producers and service companies supporting them, there is no way the good intentions of a few in industry are going to win the day without help. There is no substitute for strong regulation and vigilant enforcement.

The Environmental Defense Fund is spearheading a national campaign to make sure that public health and the environment are not compromised by the natural-gas industry. Our objectives are simple. The rules on well construction, wastewater management, and air emissions must be reformed. Full disclosure of the fracking fluids deployed at wells must be required, because communities have a right to know what chemicals are used in their midst. Claims that production activities are safe mean nothing unless data on air emissions and water quality are regularly collected and publicly shared. Lastly, emissions of methane, the main ingredient in natural gas and a powerful greenhouse gas, should be limited to 1 percent or less of the total extracted at a well. Even small leaks can undo much of the environmental benefit of substituting natural gas for coal or oil, limiting the positive role that natural gas can play in a low-carbon future.

Achieving these objectives will not be easy, but it is essential. The jury is still out on whether gas production can and will be done safely. The public will judge industry and regulators harshly if they fail to get this right.

Mark Brownstein is chief counsel for the nonprofit Environmental Defense Fund's energy program.

MEDICINE

Instant Answers

Portable diagnostic tools could offer a better outlook for TB patients, says Samuel Sia.

A teardown of the perfect portable medical diagnostic device would make the iPhone seem like rudimentary technology. Like a smartphone, it would combine electronics and software into a seamless user interface for any setting, but it would also, with laboratory-like precision, process human body fluids with fickle mixtures of biological and chemical reagents. It is little wonder that such devices have not yet made it to market.

A breakthrough device is now 20 years in the making.

Samuel Sia

Nevertheless, recent results from a compact benchtop machine called GeneXpert (see "The Machine That Will Help End TB," p. 52) make it easy to grasp how big an impact such a device could have. GeneXpert can diagnose TB drug resistance within a few hours, and it's simple enough to be used by relatively nontechnical staff in remote clinics situated close to at-risk populations. It now seems likely that this machine will offer early diagnosis for many TB patients in far-flung places, giving them a chance to be treated with effective drugs.

Yet the GeneXpert machine is still confined to laboratory settings, whereas a field-portable system would offer dramatically increased access to medical diagnostics. Startup companies are just beginning to make progress on this approach, with designs that rely on microfluidics, a technology that processes liquids inside submillimeter channels. This technology could also perform more complex tests, such as detecting multiple drug resistance to TB. A breakthrough point-of-care microfluidic device, however, is now 20 years in the making. The basic science has advanced significantly, but there is more to solving this problem, as the very different experiences of GeneXpert and the iPhone show.

Building a portable device that integrates more diverse processes than a smartphone requires focusing from the very beginning on a polished end product. That's a challenge in an industry not used to creating consumer products, for which a more natural strategy is to bring together a loose team of experts with diverse interests and an ill-defined end goal. On a clinical level, the field impact of GeneXpert highlights the need for careful local specimen collection, trial design and execution, and engagement with financial and political stakeholders. Drawing on such lessons will bring us closer to the goal of running clinical specimens from start to finish in a field setting, using miniaturized microfluidics to give patients the diagnoses they need without delay.

Samuel Sia is an associate professor of biomedical engineering at Columbia University and a founder of Claros Diagnostics, now part of pharmaceutical company Opko Health.

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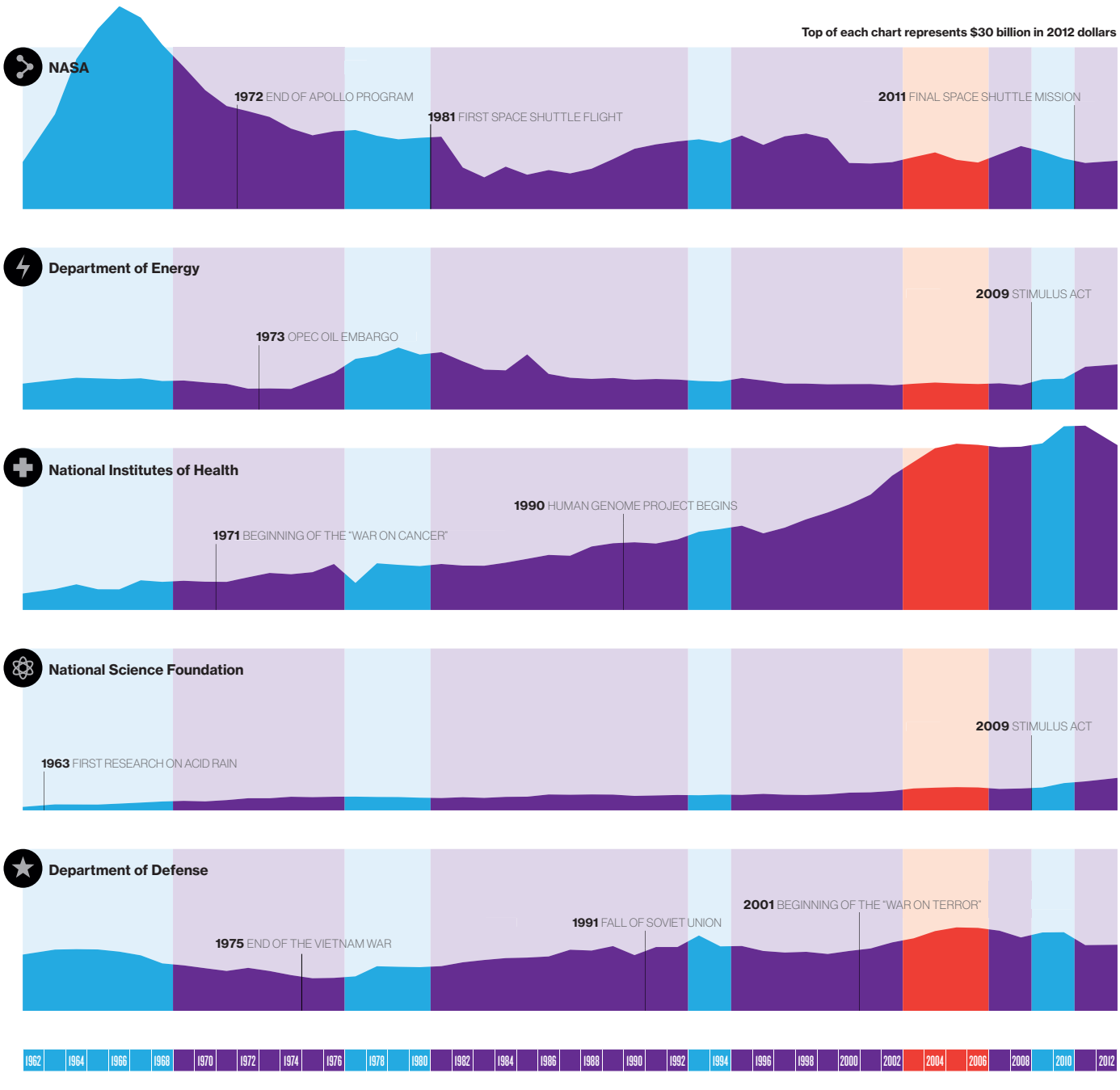

Where U.S. R&D dollars go

This chart tracks the five federal agencies that have spent the most money on research and development in science and technology over the last 50 years. Although our technological priorities have changed, R&D spending overall has been a remarkably bipartisan endeavor.

GRAPHIC BY CARL DETORRES; DATA FROM DEFENSE DEPARTMENT AND WHITE HOUSE OFFICE OF MANAGEMENT AND BUDGET

Upfront

80% 
Intel's share of all central processing units sold in PCs, servers, and mobile devices in 2000, according to the Linley Group, an analyst firm

27% 
Intel's expected share in 2012

How to Delete Regrettable Posts from the Internet

It's possible—though not always foolproof—to get embarrassing things taken down. Voluntary data-labeling standards could make it even easier.

Simson L. Garfinkel

It might seem that the Internet doesn't lose track of anything ever published online. The alleged permanence of tweets, blogs, snapshots, and instant messages worries both privacy activists and policymakers such as Viviane Reding, justice commissioner of the European Union and vice president of the European Commission. She has proposed that Europe adopt a "right to be forgotten"—a proposal that is now working its way through the EU legal process and could be law within two years.

Reding's proposal would grant EU citizens the right to withdraw their consent from online information services after the fact—allowing people to redact embarrassing things from the global information commons, even after the data had been copied to other websites. It's a controversial proposal: George Washington University law professor Jeffrey Rosen wrote in the *Stanford Law Review* that such a right could have negative implications for both free speech and journalism and could ultimately fragment the Internet. Rosen pointed out that companies like Google would need to suppress from European search queries information that had been deemed "forgotten" on the continent, even though such information would still be perfectly allowable in the United States.

The proposal might also be unnecessary. Even without a right to be forgotten, there are still many ways for information to be removed from the Web. Such methods could be made more widespread.

One possible model comes, somewhat surprisingly, from Facebook. Its "Statement of Rights and Responsibilities" says that anything you upload to the social network remains your property—posting, liking, and otherwise interacting with Facebook merely gives the service a license to the data. That license ends when the information is deleted.

Wiping away those embarrassing self-portraits you took and posted when you were drunk won't delete the copies that your friends have saved on their own hard drives. But who makes copies of photos anymore? Here's a way that the convenience of cloud-based services works in favor of privacy: they give you a single place to go and get something deleted. ⟶

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QUOTED

"Carbohydrates are not a substitute for oil. I was wrong in that, and I admit it."

—Alan Shaw, CEO of Calysta Energy, a company that intends to harness microörganisms to turn natural gas into diesel fuel. Shaw previously headed a startup that tried to make biofuels out of wood chips and other sources of cellulose, a method now considered too costly.

Facebook was created to make it easy for people to share their personal data—and as a result, people often share information without even realizing it. But Facebook also makes it easy to clean up after yourself. If you put your phone number in your profile, that number might get copied to your friends' cell phones through Facebook's application programming interface (API). But if you delete your phone number from your Facebook profile, that same API should go through your friends' phones and remove it as well. That's because Facebook's developer guidelines prohibit programs that access Facebook from making permanent copies of your personal information: software is allowed to make a "cache" copy in order to improve performance, but that copy must be linked back so that it can be kept up to date. Such license terms, designed to keep app developers dependent on Facebook, have the side effect of enforcing privacy.

It's not necessarily difficult to have information removed from Twitter, either. Even though the company's privacy policy warns that "what you say on Twitter may be viewed all around the world instantly," Twitter lets users delete their own tweets. Twitter will also take down tweets that contain harassing or private information, including credit card numbers, Social Security numbers, addresses, phone numbers, and e-mail addresses. Although it's possible that someone has made a copy, in many cases removing information effectively sends it down the memory hole.

Other big websites have similar forms for requesting that information be taken down. They do this even though they generally are not required to by U.S. law. Advertising-funded websites make so little money off any individual piece of data that it's much easier to take information down than to spend time fighting for the rights of the person who posted it.

To be sure, wiping data away from every cranny of the Internet can be challenging. But it's hard to imagine a system that could index all the world's information thoroughly enough to allow someone exercising the "right to be forgotten" to track down and eradicate every regrettable message or photo. More likely, the mechanisms for finding the data would cause more privacy violations than they would prevent.

Websites could notify others that someone's personal information had been taken down.

A better solution could be a set of standards for labeling the provenance of information on the Internet—perhaps something similar to Facebook's principle of requiring application developers to keep checking back to see whether personal information is still acceptable to use.

The HTML microdata standard currently being developed could serve this purpose. The standard is still evolving, but it will expand the ways that information in Web pages can be represented in their underlying HTML code. For example, the microdata could include tags designed to facilitate the retraction of personal information. So if you persuaded a website to take down information because it violates the site's terms of service, that website could automatically notify others that have made copies of your information, letting them know that the license to use the data has been revoked.

Such voluntary technical measures would go a long way toward improving the situation that policymakers hope to fix with a legal right to be forgotten.

TO MARKET

Flexible Gas Power Plant

7F 7-series turbine

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AVAILABILITY: Now

Solar and wind energy are clean but intermittent. To overcome that limitation, General Electric has come up with a way for power plants to quickly fire up natural gas when wind or solar energy isn't available and dial it down again when it is. The key ingredient is a 30-foot-long gas turbine (pictured) with improved compression and combustion systems. These make it possible for the turbine to ramp up from 50 megawatts to its full capacity of 250 megawatts in 10 minutes while meeting emissions standards. Using this technology instead of running a coal plant would cut carbon dioxide emissions by 2.6 million metric tons per year, GE says. The company has received $1.2 billion worth of orders for these turbines from around the world.

COURTESY OF CALYSTA ENERGY; COURTESY OF GENERAL ELECTRIC

2% Revenue that Apple devotes to R&D

15% Revenue that Nokia devotes to R&D

A Carbon Microthread That Makes Contact with the Mind

An ultrathin electrode spun from a single carbon fiber can record the activity of neurons.

By Antonio Regalado

Connecting a human brain to a computer—so that a paralyzed person could turn thoughts into actions, for instance—is as much a materials science problem as a biology problem. What kind of interface is delicate enough not to damage nerve tissue but resilient enough to last decades?

Now researchers at the University of Michigan have come up with what they call a "stealthy neural interface" made from a single carbon fiber and coated with chemicals to make it resistant to proteins in the brain. This microthread electrode, designed to pick up signals from a single neuron as it fires, is only about seven micrometers in diameter. That is 100 times thinner than the metal electrodes widely used to study animal brains, which typically stop recording after a couple of years as scar tissue builds around them.

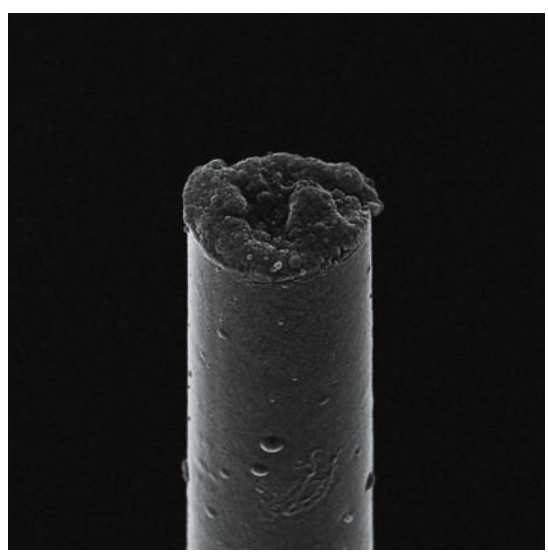
"We wanted to see if we could radically change implant technology," says Takashi Kozai, a researcher now at the University of Pittsburgh who was lead author on the paper, published in *Nature Materials*. "We want to see an electrode that lasts 70 years."

Researchers need long-lasting electrodes in order to improve brain-machine interfaces. These systems, in preliminary studies, have allowed paralyzed people to control robotic limbs or a computer mouse. By using electrodes to record the firing of many individual brain cells, scientists have learned to decode these signals so that they can represent the twitching of a rat's whiskers or a quadriplegic's effort to move his arms.

In addition to making their electrode extremely thin and resistant to proteins in the brain, the researchers also found a way to coat the tip with a polymer that helps it pick up an electrical signal.

"This was a nice demonstration that these fibers could be insulated [and] coated with an effective recording surface," says Andrew Schwartz, a Pittsburgh researcher on brain-machine interfaces, who was not involved with the work. Schwartz says such small fibers appear to work "because they seem to be 'ignored' by the brain."

He cautions, however, that it could be difficult to insert such fine, flexible electrodes into brain tissue and secure them. Recordings broke down in many of the animals studied.



An electrode made from carbon fiber thread is seven micrometers wide.

TO MARKET

Memory Upgrade

Spin-torque MRAM

COMPANY:
Everspin Technologies

PRICE:
Not yet disclosed

AVAILABILITY:
Test samples available now

COURTESY OF EVERSPIN TECHNOLOGIES

Processor speeds get more attention, but many computers are actually limited by the performance of their memory. A new data storage technology, spin-torque magnetoresistive RAM, combines the best features of the two most commonly used forms of memory: DRAM and flash. DRAM, used as short-term memory in laptops and servers, is fast and packs data densely into tiny spaces. But flash, used to store data in cell phones and some hard drives, requires less energy and is "non-volatile"—it retains information even when powered off. These new modules store bits of data as magnetic states in a way that offers fast, non-volatile storage. They could make cloud computing services more responsive.

Upfront

U.S oil production per day, in millions of barrels

OIL

10 million in the 1980s

6.9 million in 2008

11.1 million projected in 2020, thanks to newly recoverable shale deposits

To Keep Passwords Safe from Hackers, Just Break Them into Bits

Millions of passwords have been stolen from companies such as LinkedIn and Yahoo. A new approach aims to prevent future heists.

By Tom Simonite

A new way for websites and other online services to store passwords could prevent breaches like the recent one that caused 6.5 million LinkedIn users' passwords to be posted online.

That kind of data dump happens when an attacker gains access to the server storing user passwords. To make this task much harder for an attacker, researchers at the computer security company RSA have created a system that splits passwords in two and stores each half in a different location. The two halves never come together, even when a person logs in and the password is verified.

"Password storage is increasingly problematic because of the increasing frequency of breaches but also because the consequences of them have increased," says Ari Juels, who heads RSA's research labs in Cambridge, Massachusetts.

Although many Web companies encrypt passwords, so their servers don't contain the exact string that a user types, attackers have tools that can reverse this encryption. Other good security practices can be cracked as well, Juels says.

RSA calls its new scheme distributed credential protection. It's not difficult to break a password into many small pieces, storing half of them—selected at random—in one place and the rest in another. "Where the magic comes in is the ability of the system to check passwords without reassembling them," Juels says.

When a person logs into a system using distributed credential protection, the password he or she provides is split into two encrypted strings of data. Each string is then sent to one of the two password servers, where it is combined with the half of the password stored on that server to create a new string. The two servers then compare these two new strings to determine whether the password is correct. The mathematics involved make it impossible to determine the password from either of the strings, or

This would be the first time the public got to use this particular cryptographic trick.

THREE QUESTIONS

Warren East

The CEO of ARM is moving beyond mobile phones.

COURTESY OF ARM HOLDINGS

The computing business has been obsessed with processing power. Your chip company has a different focus: energy efficiency.
We have always been about efficiency, miles per gallon instead of top speed. That's actually what matters. Mobile is an easy example: you know that a phone is constrained because it's battery-powered. But [even if] you can plug [a computer] into a socket, [efficiency] is a serious issue for the world.

Microsoft is selling a tablet with an ARM-based processor. Will your chips go into many more devices that now run Intel-compatible chips?
Maybe. Someone building a PC or a tablet [now] has a choice of ARM-based supplier. That kind of competitive environment is good because suppliers are forced to be innovative. There's been a lot more innovation in mobile phones over the last 15 to 20 years than there has been in PCs.

It's often said that ARM-based chips can't support everything PCs need to do.
That's rubbish. There's nothing in the architecture which stops you [from] being at the high end of performance. In things like phones you don't want a super-high-performance [chip], because it consumes more power or real estate. But a computer [is] like having a car with a bigger fuel tank. You can make the engine do more.

—Tom Simonite

QUOTED

"Your apps can see in the dark now."

—Peter Zatloukal, head of engineering for Microsoft's Kinect for Windows program, on how software developers can now get data from the infrared camera inside the gesture-recognition system.

from both of them combined—so the password remains unknown even if an attacker can capture the strings.

The two servers involved can be set up with different operating systems and in different locations, says Juels, so stealing passwords requires mounting two separate attacks successfully. They would have to happen in short order, too, because the system periodically changes which snippets of a password are stored on each server.

RSA's new approach is a version of a technique, known as threshold cryptography, that researchers have been exploring for a while. "This would be the first time that it is deployed to the general public," says Dan Boneh, a professor at Stanford University who has researched such designs. Threshold cryptography is also used behind the scenes by companies known as certificate authorities, which issue the digital security certificates that help computers and Web browsers know which servers to trust—for example, when logging on to a banking website.

One way to boost the effectiveness of the approach would be to split passwords or secrets across more than just two servers, says Boneh. Juels says RSA plans to make that possible in the future.

However, Boneh notes, there are still plenty of ways for a person's secrets to be stolen. RSA's system can't prevent situations where a user's password can be guessed or stop it from being stolen directly from a computer with the help of malware that records keystrokes.

COURTESY OF MICROSOFT; REUTERS/INTS KALNINS

How Improved Batteries Will Make Electric Vehicles Competitive

It will probably take a decade, but improvements to lithium-ion batteries could lead to much cheaper EVs.

By Kevin Bullis

There are plenty of reasons why electric cars aren't catching on, but one problem is certain: the batteries cost far too much. For electric vehicles and plug-in hybrids to compete with gas-powered cars, battery prices need to drop by between 50 and 80 percent, according to recent estimates by the U.S. Department of Energy.

Getting there might require inventing entirely new kinds of batteries. But there's also a strong case that it could be done merely with improvements to the lithium-ion batteries that power the current generation of electric vehicles.

For example, one startup, Envia Systems, has built prototype lithium-ion battery cells that store about twice the energy of the best conventional lithium-ion batteries and can be recharged hundreds of times. Crucially, they're similar enough to the conventional version to be made on existing manufacturing equipment.

The technology still needs work, and it could take several years to start appearing in cars, the company says. But it's far from the only possible improvement to ⟶

Electric cars such as the Nissan Leaf are unlikely to sell widely at their current prices.

Upfront

QUOTED

"We expect these expeditions to be the equivalent of the Olympics for foreign countries."

—Alan Stern, a former NASA science chief who has founded a company to take people to the moon. He believes many countries would pay for the prestige of having a presence there.

lithium-ion technology. Jeff Dahn, who does research on lithium-ion batteries at Dalhousie University, says electric cars like the Nissan Leaf and the Chevrolet Volt use a special type of flat lithium-ion cell made with recently developed equipment that is still relatively slow. More conventional cylindrical lithium-ion cells cost roughly half as much to make because they use much faster equipment and are produced at a larger scale. Dahn believes that many of the components, such as a plastic film that separates electrodes in a battery, are overpriced. "You can't tell me separator cost can't come down," he says.

Indeed, although the battery pack for the Leaf costs about $12,000, a recent study by McKinsey suggests that the cost could fall below $4,000 by 2025 with just two changes: increasing the scale of battery production, which would force down component costs through competition, and approximately doubling the energy density of batteries, which would reduce material costs.

Not everyone agrees that today's lithium-ion batteries can readily reach the price level needed for electric vehicles to compete with gas-powered ones. Toyota, for one, is investigating more dramatic changes in battery design. One technology it's developing replaces the liquid electrolyte in a conventional lithium-ion battery with a solid material. That allows for a number of changes in the battery design that could shrink the system and lower the cost. These solid-state batteries and other technologies could cut the size of a battery pack by 80 percent, according to Toyota. Sakti3, a startup with close ties to General Motors, is also developing solid-state batteries and recently started shipping prototypes to potential customers for testing, says CEO Ann Marie Sastry.

24M, an early-stage startup based in Cambridge, Massachusetts, is taking a different approach. Rather than an all-solid battery, the company is developing a cross between a battery and a fuel cell, in which the battery electrodes take the form of a sludgy liquid that can be pumped around. The energy storage material could be held in inexpensive tanks and then pumped into a small device to generate power.

Lithium-ion batteries will have a long time to improve before other technologies are ready.

Though their design is novel, solid-state batteries and 24M's technology still use a familiar lithium-ion chemistry, which could make them less risky to commercialize than more radical approaches. True alternatives to lithium-ion batteries (the list is long, including lithium-sulfur, lithium-air, zinc-air, and magnesium-ion chemistries) have theoretical energy densities several times that of today's electric-car batteries. But each seems to have its own problems. For example, lithium-air batteries, which could store 10 times as much energy as conventional lithium-ion batteries (approaching the energy density of gasoline), use lithium metal, which can be very dangerous, and they can't be recharged very many times.

Even if the problems posed by the more experimental technologies can be solved in the lab, it could take decades to develop the manufacturing techniques to reliably make the batteries in the large numbers needed to power cars. All this means that conventional lithium-ion battery technologies will have a long time to improve before a real competitor comes along.

TO MARKET

Smarter Credit Card

Display Card

COMPANY: MasterCard

PRICE: Free for certain cardholders

AVAILABILITY: January

Unlike the humble check, the credit card is adapting to the world of online commerce. To improve the security of Internet banking services, MasterCard has upgraded some of its familiar plastic cards with a number pad and small display. To access their accounts online, cardholders must enter a string of numbers on their card's touch pad. The card's display then produces a one-time pass code for use online. The same basic design can support more sophisticated features; for example, it might display the remaining balance on a card after each use. It's initially being offered to customers of Singapore's Standard Chartered bank.

COURTESY OF GOLDEN SPIKE; COURTESY OF MASTERCARD

Q+A Bono

The musician and activist explains how technology can make the world so much better.

To say that Bono is the lead singer of the rock band U2 is like saying that Thomas Edison invented the record player: it leaves out a lot of biography. The 52-year-old Irishman (born Paul Hewson) is also a technology investor and an activist who cofounded the ONE and (RED) organizations, which are devoted to eradicating extreme poverty and AIDS. He has spent years urging Western leaders to forgive the debts of poor nations and to increase funding for AIDS medicines in Africa.

Bono answered questions over e-mail from *MIT Technology Review*'s deputy editor, Brian Bergstein, about the role that technologies—from vaccines to information services—can play in solving our biggest problems.

It's 2013, and millions of people are still short of food or proper medical care. Have technologists overpromised?

The tech that's been delivered has been staggering in its measurable achievements. For example, antiretrovirals, a complex 15-drug AIDS regimen compressed into one pill a day (now saving eight million lives); the insecticide-treated bed net (cut malaria deaths by half in eight countries in Africa in the last three years); kids' vaccinations (saved 5.5 million lives in the last decade); the mobile phone, the Internet, and spread of information—a deadly combination for dictators, for corruption.

But to maximize the massive effect technology can have, you need a network of efforts, a system of interventions, supported by citizens who share social capital. That's what drives substantial progress sustainably. There is no silver bullet to ending extreme poverty and disease, no magic technology. That takes commitment, a lifetime of it, plus resources, political will, and people standing up to demand it. Technology provides the means, however.

What should be the role of technology in making a better world? Are some problems beyond its reach, like poverty?

Technology has already helped tackle extreme poverty in Africa. Extreme poverty is the empirical condition of living on under $1.25 a day. Nelson Mandela once demanded we be the "great generation" to beat extreme poverty, noting how we have the technology and resources to achieve this extraordinary vision. And we do. We could achieve it by 2030, maybe before. The digital revolution that we are living through, the rapid advances in health and agrotechnology—these things have become core weapons in responding to Mandela's clarion call. They enable people to get on with it themselves, to fight their way out of the condition they find themselves in. In Africa, things are changing so rapidly. What's been a slow march is suddenly picking up pace in ways we could not have imagined even 10 years ago. Innovations like farmers using mobile phones to check seed prices, for banking, for sending payments ... to the macro effect we saw with the Arab Spring thanks to Facebook and Twitter.

But people can use technology for bad as well as good. The social systems and the social capital within networks must be strong and positive to nurture a progressive use of technology. Let's be honest.

You admired Steve Jobs. Did he make the world better or just make nice computers?

I think a large part of the reason Apple and Steve Jobs have beguiled so many is that they are a gigantic company that put greatness ahead of the bottom line, believing that great profitability would follow in the long term. Steve was an extremely tough deal maker, and if that was the only side you saw, I can imagine that a more fearsome profile would emerge. But the reason why I, and others who got a glimpse of him personally, were such believers was his clear thinking. Great ideas to me are like great melodies. They are instantly recognizable, memorable, and have some sort of inevitable arc. In the music world, it's hard to imagine there being a better melody to "I want to hold your hand." In the tech world, it's hard to imagine there being any better form or function to a lot

Bono with Bill Clinton in New York City in 2011; with Steve Jobs in San Jose, California, in 2004; and with nurse Abena Wonka at a community clinic in Accra, Ghana, in 2006.

of Apple's products. It's as if they've always existed. It's that kind of inevitability Steve could spot. With Jony Ive's designs, with Avie Tevanian's operating systems, etc. In amongst the noise, the yearning for that clear tone, or in Apple's case, pure white.

He told me he would love to spend more time on philanthropy and would get to it one day. He wasn't interested in half doing it, as is obvious with his personality. Still, Apple very quietly has contributed more than $50 million to the Global Fund to Fight AIDS, TB, and Malaria through the sale of (RED) iPods, Nanos, etc. They are the biggest corporate donor. Tim Cook is passionate about this stuff. By attaching themselves to what is, in recessionary times at home, an unpopular emergency (people dying in far-off places because they can't afford AIDS drugs), he and Apple have really helped to keep the heat on the issue.

If you had a budget equivalent to the one that put astronauts on the moon, what problems would you try to solve?

There's an exciting thought. The Apollo program in its day was 4 percent of the federal budget. All U.S. overseas assistance is just 1 percent, with 0.7 percent going to issues that affect the poorest people. I believe that extreme poverty is the biggest challenge we have. That term is a complex one, but on many aspects, we know what works. For example, with Apollo-level resources, you could finish the job on HIV/AIDS. Get rid of it, done. Malaria too. You could vaccinate every kid against deadly diseases we in the West hardly think about. You could boost farming productivity in Africa, which is twice as effective at reducing poverty as anything else. Lastly, you could kick-start electrifying Africa. Electricity means small businesses can function and hire people, medicines can be refrigerated, kids can study after the sun sets. Electrifying Africa would inspire the kind of economic development that would mean, eventually, they wouldn't need our 4 percent or 1 percent. Aid is just a bridge, but where there are troubled waters, it's needed.

I should add that without fighting corruption at the same time as spending the Apollo money, you'd be in danger of tossing it up to the moon. Corruption is deadly, but there's a vaccine for that too—it's called transparency. Daylight. It's much harder to rip people off when they know what's going

Bono and Senator Barack Obama at the National Prayer Breakfast in Washington in 2006.

on. We can gather and disseminate data in all sorts of ways, giving a whole new meaning to the word "accountability."

You've worked closely with Democrats and Republicans. How can they get more done in a politically polarized atmosphere?

For nearly 15 years I've regularly been a pest in Washington, D.C., first an amateur with some smart company, now a pretty professional one with an army of the best and brightest at the ONE Campaign. From the start I was told how the Capitol had never been so polarized, and how nothing is getting done, parties are pounding each other out of effectiveness, etc. Fifteen years hearing the same thing. But every time I've been there, I've met with politicians who are willing to rise above that, to reach across the aisle to get things done when it comes to the most vulnerable people on our planet. Their plight lifts people above the negativity, reminds officials why they came to Washington in the first place—to get real things done that help people help themselves. In the last two elections, the world's poor and foreign aid have not been used as a pawn in the political game. In fact, they've been the one thing that candidates can actually agree on. That didn't just happen. A more savvy media and public demanded it.

How can President Obama best improve the state of the world in his second term?

President Obama has already set a strong course on strengthening food security in poor countries, and he's built on President [George W.] Bush's legacy on AIDS. Both of these initiatives need to be accelerated. With global leadership to promote partnerships with poorer countries, and with the right resources, we can end a few things that just don't belong in the 21st century. Like AIDS, like malaria, like polio.

"With data informing our course we can describe the kind of world we want to live in and then without airy-fairyness or wishful thinking go after it."

The president has also championed transparency in the oil, gas, and mineral extraction sector, shedding much-needed light on some of the murkier dealings that go on. Where there is great wealth under the ground in some of the poorest countries, the benefits belong in the hands of all those who live there.

Electrification—that'd be a good use of his leadership. Poorer countries have the advantage of being able to leapfrog, as they've done with communications infrastructure. They can do this with more efficient, cleaner forms of tech like geothermal, hydro, solar, carbon capture.

Do you despair? If not, why not?

Like any parent, I wonder what kind of world we're leaving behind. But I've also been blessed to be involved in some great movements that helped bring major challenges—like debt or AIDS or malaria—from the margins to the mainstream. These social movements are the things that make the real difference, people from different walks of life coming together to stand up for what they believe in. Whether they do it by marching, by writing, by tweeting, by posting, by singing, or by going to jail. It's hard not to be an optimist when you see what happens when people join forces.

Right now, though, I think things do hang in the balance. I just heard about a report that predicts the world by 2030 will be fracturing further as rising populations and consumption patterns compete over scarce natural resources. That's a real recipe for conflict and instability. But it's avoidable. I'm confident we can overcome the worst trends—but only if we get even better at building innovative networks to do more of what works and less of what doesn't.

How might this happen? Collecting more data and more open data so we can drill down further on knowing what to do. Continued technological innovations, no question, on more and more fronts. The connectivity of social media, harnessed for action, not apathy. Hundreds of thousands marched in the "Drop the Debt" campaign, and now an extra 51 million kids in Africa are going to school because of monies freed up by debt cancellation—it's a staggering number. That wouldn't have happened without people across the globe demanding it. The tools that technology provides mean we know more and we understand more about previously-thought-unsolvable problems. With this data informing our course we can describe the kind of world we want to live in and then without airy-fairyness or wishful thinking go after it. It's the greatest opportunity that has ever been offered any generation. Which is the truth. Wow.

ASSOCIATED PRESS/RON EDMONDS

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Arkansas's Fayetteville Shale is among the rich deposits of natural gas that are now accessible using advanced drilling and hydrofracturing technologies.

Drilling for Shale Gas

By David Rotman
Photographs by Beth Perkins

Southwestern Energy's drilling rig #26 at a site north of Conway, Arkansas, will bore down several thousand feet before boring horizontally for thousands more.

After drilling a well, a worker prepares the rig to be moved to another site. The drill bit above, made of tungsten carbide and synthetic diamonds, was designed for the shale.

In the yard adjacent to the well is the apparatus needed to support the complex drilling operations, including the electric equipment that powers the rig. In an enclosed cabin on the drilling platform (below), Waylon Boad can monitor the drilling, using information from a deck of advanced gauges and video screens. Below left, pipes head out from multiple wells to a compressor, where the gas will be pressurized and sent to transmission pipelines.

A short distance from where rig #26 is finishing up, a drilled well is being hydrofractured. Gene Yates supervises the procedure, in which water at up to 8,000 pounds per square inch is pumped into the well and out through holes in the horizontal pipe, "fracturing" the shale and allowing gas trapped in it to flow into the pipe.

Fresh water for fracking is pumped to the site and treated by means of an ozone-based process to destroy bacteria (middle). In a trailer next to the wells (left), workers monitor the fracking, keeping a close eye on the pressure.

The three blue wells below are surrounded by white trucks at the fracking site; water from the trucks is pumped down the wells. Sand is used as a "proppant" to keep the microfractures in the shale open.

After a well is fracked, it's ready for production (top). The gas is piped to condensers (center), where water is removed before the gas moves to pipelines. An artificial pond (bottom) supplies water needed for fracking yet more wells.

Despite the glut of cheap natural gas in the United States, business is booming for Southwestern. Million-dollar fracking trucks in its brand-new fleet await assignments.

"TECHNOLOGY HAS GIVEN POLITICS BACK ITS SOUL"

Joe Trippi, shown at Howard Dean's Vermont headquarters in 2003, managed Dean's 2004 presidential campaign.

A longtime political operative cheers the innovations of Obama 2012, saying they restored the primacy of the individual voter.

By **JOE TRIPPI**

IN 1979, I was an aeronautical-engineering major at San Jose State University, sneaking time in the laser lab to make holograms or running over to the computer lab in the middle of the night to try my hand at IBM punch cards and Fortran. In between classes and on weekends, I volunteered in local political campaigns and thought of changing my major to political science. I was 23 years old and trying to figure out what I wanted to do with my life. What would change people's lives more, I thought: technology or politics?

Technology seemed full of promise yet somehow soulless. Heart and soul was what I found when I volunteered. So, late in 1979, I got in my car, leaving my most prized possession—a Tandy TRS-80 microcomputer—with a friend, and drove to Iowa to become a $15-a-day field organizer for Ted Kennedy's campaign for president.

In Iowa, the Kennedy team was harnessing the most advanced technology then available to a presidential campaign: the telephone call combined with meticulous use of three-by-five index cards. A paid phone bank would call registered Democrats and independents and ask them whom they intended to vote for in the upcoming Iowa caucuses. An index card would be created with the voter's name, address, and phone number—and a code number for the person's answer to that one question, handwritten on the card. A "1" meant the voter was for Kennedy; "2" that the voter was leaning to Kennedy; "3" that a voter was undecided. Worst was "4": it meant the voter was supporting our opponent, the president of the United States, Jimmy Carter. When newly minted Kennedy organizers like me arrived in Iowa, we were told what county we would be organizing—and were handed shoeboxes of index cards that had been coded.

From that point you did whatever you thought worked. If some line of argument moved an undecided "3" in your candidate's direction, you kept using that argument; but there wasn't much of a way to tell other organizers you had stumbled on a persuasive message. You called any updated code numbers in to your assigned regional headquarters every night. You never learned what it did with them.

Until the Obama 2012 campaign, none of this got much better as time wore on. The three-by-five card would give way to computer-generated printouts over time, but the basic coding system in politics stayed the same. Worse, at the time I joined politics, campaigns were starting to invest less and less in field organization and voter contact. Television ads were growing in importance, and even as early as the 1980 presidential campaign, resources were being taken away from meeting and talking with voters at their doors and redirected toward reaching those same voters with 30-second spots in their living rooms. As a consequence, politics started to lose its soul, which is the active participation of ordinary voters in elections.

In 1982 I was Los Angeles mayor Tom Bradley's deputy campaign manager when he sought the governorship of California. I tried to talk the campaign into buying a PDP-series computer from Digital Equipment Corporation (DEC) to use in targeting our direct-mail fund-raising appeals and running our voter identification data and get-out-the-vote targets. No one had installed a computer for a political campaign before, and my colleagues didn't want to risk money on an untested idea. I took my life savings, bought the machine myself, and installed it on my own. We used it to raise hundreds of thousands of dollars from direct mail, and we built an enormous database of California voters for targeting our field operations.

We had the data: we knew which voters were wholly ours and which were less likely to turn out without our effort. And we had budgeted $2 million for our get-out-the-vote organization.

A few weeks before Election Day, our polling showed that we had slipped behind our Republican opponent, George Deukmejian. Our pollster told us that unless the campaign spent another $2 million on statewide television, we would lose. Suddenly, all our targeting and voter identification was for naught: the campaign took the $2 million we had set aside for getting out the vote and bet it all on television ads.

On election night, I had the DEC PDP look at our data and the data from the California Secretary of State's Office as precincts reported. All three broadcast television networks declared Bradley the winner on the basis of exit polls. But the computer didn't blink; within minutes of the polls closing, it belched out a projection that Bradley would lose by 100,000 votes. Months later, when the final results were in, it would turn out that we lost by about 93,000 votes—roughly three votes per precinct.

Decisions like this were made in campaign after campaign, within both parties, for the next 30 years. Television won every time. Poll-driven television ads sucked the heart and soul out of politics without much challenge. But during the very years that politics stagnated, technology evolved to allow people to share ideas and stories or sell and buy things from each other in ways that really improved their lives. By late 2002, political professionals from both sides of the political spectrum believed that it might be possible to take on the top-down, money-driven, television-ad-centric approach to politics and instead use technology to build a bottom-up, people-centered politics.

The 2004 presidential bid of Howard Dean, the former governor of Vermont, attracted former McCain 2000 staffers, old Kennedy hands, activists from both parties, and ordinary people from across the country who wanted to build a different

RICK FRIEDMAN/GETTY IMAGES

kind of political campaign: one that would empower people to organize themselves. They hoped to return grassroots activism to the political process and encourage people to participate actively in politics instead of watching it on TV as consumers. The campaign also drew me: I was its campaign manager.

The Dean campaign was a great, pioneering effort, but it happened too soon. In 2003, there were 55 million households in the United States with Internet access, but broadband was rare, and neither YouTube nor Facebook nor Twitter yet existed. The iPhone, the first popular smartphone, would not be released until 2007. The Dean campaign would break President Bill Clinton's fund-raising records and build a nationwide organization of 650,000 people, more than had joined any previous presidential campaign; but it would take one more presidential campaign cycle for the rocket engines of social networks to benefit from the fuel of broadband and provide sufficient thrust for the new model to reach escape velocity.

By 2007, Americans had begun participating in politics in numbers no one had imagined possible. TV ads would have almost nothing to do with Barack Obama's election, although more would be spent on them than ever before. Hillary Clinton lost the Democratic nomination for the simple reason that she ran an old-fashioned campaign. But Obama's victory in 2008 was remarkable not only because he raised a half-billion dollars online and had over 13 million people sign on to his campaign. His win in 2008 was most remarkable because it allowed his campaign staff to do something truly novel in 2012: build a national campaign armed with big data.

As Sasha Issenberg describes at length in "A More Perfect Union" (see p. 38), big data gave Obama 2012 the names of all 69 million people who voted for the candidate in 2008 and allowed the campaign to rebuild that winning coalition, vote by vote. Big data told the campaign which voters were undecided, and even which voters with otherwise Republican attitudes could be swayed to vote for the president. The campaign spent over $100 million developing the biggest network of people in political history. Millions of Americans heard from other Americans about issues that mattered to them. Those conversations were more powerful than the billions of dollars spent on TV ads. It requires no hyperbole to say that Obama 2012 changed everything.

Mitt Romney's campaign and its allies made the same mistake Hillary Clinton made in 2008: they ran a top-down campaign preoccupied with buying television ads and influencing the media. As a professional political strategist, I was surprised: I didn't think anyone would try it again. But the GOP didn't understand the new politics, and the election was a rout. One dejected Romney staffer said after the election, "We weren't even running in the same race."

For several reasons, the Republican Party may struggle to catch up. First, it is woefully behind in building a national network. Second, the GOP is unloved by a key demographic group it will need: the technically educated, creative young people who like to build software and do data analysis. Finally, there is something about Republican top-down message discipline that discourages the party's members from letting go a little and allowing a grassroots organization to grow. The most successful popular conservative movement of recent years, the Tea Party, distrusts the Republican establishment almost as much as it dislikes Democrats.

But the outstanding fact of the 2012 election is that the pollsters, consultants, advisors, and political gatekeepers who guarded the old way of doing politics lost bigger than Mitt Romney or the Republican Party itself. There is perhaps no human activity where power is so jealously protected as it is in professional politics. The old guard will try to demonstrate its usefulness for a few more elections, and some will doubtless adapt. But its dominance has passed. The 23-year-old organizers who listen to people, and work with campaigns to measure the persuasive effectiveness of different messages, will be knocking on doors in the midterm elections and in the presidential election of 2016.

Will the methods that won an election be used for governance? During President Obama's first term in office, his administration did not effectively use Organizing for America (the community network the Democratic National Committee created after the 2008 victory) to mobilize support for his legislative agenda. But as I write, the network is asking Americans to pressure Congress to pass the president's debt proposals. Second-term presidents may not be so lame with big data and a large network of supporters.

All these changes in democratic politics will be profound, although not all the consequences will be good. New technologies can manipulate, empower, or do both. There will be plenty of actors in both politics and business who will use the innovations of the Obama 2012 campaign as tools to manipulate people. But for me, right now, it feels as if technology has empowered people and given politics back its soul.

Joe Trippi is a Democratic political strategist who worked on the presidential campaigns of Ted Kennedy, Walter Mondale, Gary Hart, Dick Gephardt, Jerry Brown, and John Edwards. From 1989 to 2003, he was an e-commerce and cyber-security consultant in Silicon Valley before returning to politics to become the campaign manager for Howard Dean's 2004 presidential bid. More recently, he produced the media for Jerry Brown's successful 2010 campaign for governor of California, and has advised candidates and governments in Europe, Africa, and the Middle East.

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How President Obama's campaign used big

TWO YEARS AFTER BARACK Obama's election as president, Democrats suffered their worst defeat in decades. The congressional majorities that had given Obama his legislative successes, reforming the health-insurance and financial markets, were swept away in the midterm elections; control of the House flipped and the Democrats' lead in the Senate shrank to an ungovernably slim margin. Pundits struggled to explain the rise of the Tea Party. Voters' disappointment with the Obama agenda was evident as independents broke right and Democrats stayed home. In 2010, the Democratic National Committee failed its first test of the Obama era: it had not kept the Obama coalition together.

But for Democrats, there was bleak consolation in all this: Dan Wagner had seen it coming. When Wagner was hired as the DNC's targeting director, in January of 2009, he became responsible for collecting voter information and analyzing it to help the committee approach individual voters by direct mail and phone. But he appreciated that the raw material he was feeding into his statistical models amounted to a series of surveys on voters' attitudes and preferences. He asked the DNC's technology department to develop software that could turn that information into tables, and he called the result Survey Manager.

That fall, when a special election was held to fill an open congressional seat in upstate New York, Wagner successfully predicted the final margin within 150

Illustrations by Justin Metz

data to rally individual voters.

By SASHA ISSENBERG

votes—well before Election Day. Months later, pollsters projected that Martha Coakley was certain to win another special election, to fill the Massachusetts Senate seat left empty by the death of Ted Kennedy. But Wagner's Survey Manager correctly predicted that the Republican Scott Brown was likely to prevail in the strongly Democratic state. "It's one thing to be right when you're going to win," says Jeremy Bird, who served as national deputy director of Organizing for America, the Obama campaign in abeyance, housed at the DNC. "It's another thing to be right when you're going to lose."

It is yet another thing to be right *five months* before you're going to lose. As the 2010 midterms approached, Wagner built statistical models for selected Senate races and 74 congressional districts. Starting in June, he began predicting the elections' outcomes, forecasting the margins of victory with what turned out to be improbable accuracy. But he hadn't gotten there with traditional polls. He had counted votes one by one. His first clue that the party was in trouble came from thousands of individual survey calls matched to rich statistical profiles in the DNC's databases. Core Democratic voters were telling the DNC's callers that they were much less likely to vote than statistical probability suggested. Wagner could also calculate how much the Democrats' mobilization programs would do to increase turnout among supporters, and in most races he knew it wouldn't be enough to cover the gap revealing itself in Survey Manager's tables.

His congressional predictions were off by an average of only 2.5 percent. "That was a proof point for a lot of people who don't understand the math behind it but understand the value of what that math produces," says Mitch Stewart, Organizing for America's director. "Once that first special [election] happened, his word was the gold standard at the DNC."

The significance of Wagner's achievement went far beyond his ability to declare winners months before Election Day. His approach amounted to a decisive break with 20th-century tools for tracking public opinion, which revolved around quarantining small samples that could be treated as representative of the whole. Wagner had emerged from a cadre of analysts who thought of voters as individuals and worked to aggregate projections about their opinions and behavior until they revealed a composite picture of everyone. His techniques marked the fulfillment of a new way of thinking, a decade in the making, in which voters were no longer trapped in old political geographies or tethered to traditional demographic categories, such as age or gender, depending on which attributes pollsters asked about or how consumer marketers classified them for commercial purposes. Instead, the electorate could be seen as a collection of individual citizens who could each be measured and assessed on their own terms. Now it was up to a candidate who wanted to lead those people to build a campaign that would interact with them the same way.

After the voters returned Obama to office for a second term, his campaign became celebrated for its use of technology—much of it developed by an unusual team of coders and engineers—that redefined how individuals could use the Web, social media, and smartphones to participate in the political process. A mobile app allowed a canvasser to download and return walk sheets without ever entering a campaign office; a Web platform called Dashboard gamified volunteer activity by ranking the most active supporters; and "targeted sharing" protocols mined an Obama backer's Facebook network in search of friends the campaign wanted to register, mobilize, or persuade.

But underneath all that were scores describing particular voters: a new political currency that predicted the behavior of individual humans. The campaign didn't just know who you were; it knew exactly how it could turn you into the type of person it wanted you to be.

The Scores

FOUR YEARS EARLIER, DAN WAGNER HAD been working at a Chicago economic consultancy, using forecasting skills developed studying econometrics at the University of Chicago, when he fell for Barack Obama and decided he wanted to work on his home-state senator's 2008 presidential campaign. Wagner, then 24, was soon in Des Moines, handling data entry for the state voter file that guided Obama to his crucial victory in the Iowa caucuses. He bounced from state to state through the long primary calendar, growing familiar with voter data and the ways of using statistical models to intelligently sort the electorate. For the general election, he was named lead targeter for the Great Lakes/Ohio River Valley region, the most intense battleground in the country.

After Obama's victory, many of his top advisors decamped to Washington to make preparations for governing. Wagner was told to stay behind and serve on a post-election task force that would review a campaign that had looked, to the outside world, technically flawless.

In the 2008 presidential election, Obama's targeters had assigned every voter in the country a pair of scores based on the probability that the individual would perform two distinct actions that mattered to the campaign: casting a ballot and supporting Obama. These scores were derived from an unprecedented volume of ongoing survey work. For each battleground state every week, the campaign's call centers conducted 5,000 to 10,000 so-called short-form interviews that quickly gauged a voter's preferences, and 1,000 interviews in a long-form version that was more like a traditional poll. To derive individual-level predictions, algorithms trawled for patterns between these opinions and the data points the campaign had assembled for every voter—as many as one thousand variables each, drawn from voter registration records, consumer data warehouses, and past campaign contacts.

This innovation was most valued in the field. There, an almost perfect cycle of microtargeting models directed volunteers to scripted conversations with specific voters at the door or over the phone. Each of those interactions produced data that streamed back into Obama's servers to refine the models pointing volunteers toward the next door worth a knock. The efficiency and scale of that process put the Democrats well ahead when it came to profiling voters. John McCain's campaign had, in most states, run its statistical model just once, assigning each voter to one of its microtargeting segments in the summer. McCain's advisors were unable to recalculate the probability that those voters would support their candidate as the dynamics of the race changed. Obama's scores, on the other hand, adjusted weekly, responding to new events like Sarah Palin's vice-presidential nomination or the collapse of Lehman Brothers.

WHY IT MATTERS

The Obama 2012 campaign used data analytics and the experimental method to assemble a winning coalition vote by vote. In doing so, it overturned the long dominance of TV advertising in U.S. politics and created something new in the world: a national campaign run like a local ward election, where the interests of individual voters were known and addressed.

Dan Wagner, the chief analytics officer for Obama 2012, led the campaign's "Cave" of data scientists.

Within the campaign, however, the Obama data operations were understood to have shortcomings. As was typical in political information infrastructure, knowledge about people was stored separately from data about the campaign's interactions with them, mostly because the databases built for those purposes had been developed by different consultants who had no interest in making their systems work together.

But the task force knew the next campaign wasn't stuck with that situation. Obama would run his final race not as an insurgent against a party establishment, but as the establishment itself. For four years, the task force members knew, their team would control the Democratic Party's apparatus. Their demands, not the offerings of consultants and vendors, would shape the marketplace. Their report recommended developing a "constituent relationship management system" that would allow staff across the campaign to look up individuals not just as voters or volunteers or donors or website users but as citizens in full. "We realized there was a problem with how our data and infrastructure interacted with the rest of the campaign, and we ought to be able to offer it to all parts of the campaign," says Chris Wegrzyn, a database applications developer who served on the task force.

Wegrzyn became the DNC's lead targeting developer and oversaw a series of costly acquisitions, all intended to free the party from the traditional dependence on outside vendors. The committee installed a Siemens Enterprise System phone-dialing unit that could put out 1.2 million calls a day to survey voters' opinions. Later, party leaders signed off on a $280,000 license to use Vertica software from Hewlett-Packard that allowed their servers to access not only the party's 180-million-person voter file but all the data about volunteers, donors, and those who had interacted with Obama online.

Many of those who went to Washington after the 2008 election in order to further the president's political agenda returned to Chicago in the spring of 2011 to work on his reëlection. The chastening losses they had experienced in Washington separated them from those who had known only the ecstasies of 2008. "People who did '08, but didn't do '10, and came back in '11 or '12—they had the hardest culture clash," says Jeremy Bird, who became national field director on the reëlection campaign.

But those who went to Washington and returned to Chicago developed a particular appreciation for Wagner's methods of working with the electorate at an atomic level. It was a way of thinking that perfectly aligned with their simple theory of what it would take to win the president reëlection: get everyone who had voted for him in 2008 to do it again. At the same time, they knew they would need to succeed at registering and mobilizing new voters, especially in some of the fastest-growing demographic categories, to make up for any 2008 voters who did defect.

Obama's campaign began the election year confident it knew the name of every one of the 69,456,897 Americans whose votes had put him in the White House. They may have cast those votes by secret ballot, but Obama's analysts could look at the Democrats' vote totals in each precinct and identify the people most likely to have backed him. Pundits talked in the abstract about reassembling Obama's 2008 coalition. But within the campaign, the goal was literal. They would reassemble the coalition, one by one, through personal contacts.

Photograph by Chris Lake

Obama's strategists grew confident they were no longer restricted

The Experiments

WHEN JIM MESSINA ARRIVED IN CHICAGO as Obama's newly minted campaign manager in January of 2011, he imposed a mandate on his recruits: they were to make decisions based on measurable data. But that didn't mean quite what it had four years before. The 2008 campaign had been "data-driven," as people liked to say. This reflected a principled imperative to challenge the political establishment with an empirical approach to electioneering, and it was greatly influenced by David Plouffe, the 2008 campaign manager, who loved metrics, spreadsheets, and performance reports. Plouffe wanted to know: How many of a field office's volunteer shifts had been filled last weekend? How much money did that ad campaign bring in?

But for all its reliance on data, the 2008 Obama campaign had remained insulated from the most important methodological innovation in 21st-century politics. In 1998, Yale professors Don Green and Alan Gerber conducted the first randomized controlled trial in modern political science, assigning New Haven voters to receive nonpartisan election reminders by mail, phone, or in-person visit from a canvasser and measuring which group saw the greatest increase in turnout. The subsequent wave of field experiments by Green, Gerber, and their followers focused on mobilization, testing competing modes of contact and get-out-the-vote language to see which were most successful.

The first Obama campaign used the findings of such tests to tweak call scripts and canvassing protocols, but it never fully embraced the experimental revolution itself. After Wagner moved to the DNC, the party decided it would start conducting its own experiments. He hoped the committee could become "a driver of research for the Democratic Party."

To that end, he hired the Analyst Institute, a Washington-based consortium founded under the AFL-CIO's leadership in 2006 to coördinate field research projects across the electioneering left and distribute the findings among allies. Much of the experimental world's research had focused on voter registration, because that was easy to measure. The breakthrough was that registration no longer had to be approached passively; organizers did not have to simply wait for the unenrolled to emerge from anonymity, sign a form, and, they hoped, vote. New techniques made it possible to intelligently profile nonvoters: commercial data warehouses sold lists of all voting-age adults, and comparing those lists with registration rolls revealed eligible candidates, each attached to a home address to which an application could be mailed. Applying microtargeting models identified which nonregistrants were most likely to be Democrats and which ones Republicans.

The Obama campaign embedded social scientists from the Analyst Institute among its staff. Party officials knew that adding new Democratic voters to the registration rolls was a crucial element in their strategy for 2012. But already the campaign had ambitions beyond merely modifying nonparticipating citizens' behavior through registration and mobilization. It wanted to take on the most vexing problem in politics: changing voters' minds.

The expansion of individual-level data had made possible the kind of testing that could help do that. Experimenters had typically calculated the average effect of their interventions across the entire population. But as campaigns developed deep portraits of the voters in their databases, it became possible to measure the attributes of the people who were actually moved by an experiment's impact. A series of tests in 2006 by the women's group Emily's List had illustrated the potential of conducting controlled trials with microtargeting databases. When the group sent direct mail in favor of Democratic gubernatorial candidates, it barely budged those whose scores placed them in the middle of the partisan spectrum; it had a far greater impact upon those who had been profiled as soft (or nonideological) Republicans.

That test, and others that followed, demonstrated the limitations of traditional targeting. Such techniques rested on a series of long-standing assumptions—for instance, that middle-of-the-roaders were the most persuadable and that infrequent voters were the likeliest to be captured in a get-out-the-vote drive. But the experiments introduced new uncertainty. People who were identified as having a 50 percent likelihood of voting for a Democrat might in fact be torn between the two parties, or they might look like centrists only because no data attached to their records pushed a partisan prediction in one direction or another. "The scores in the middle are the people we know less about," says Chris Wyant, a 2008 field organizer who became the campaign's general election director in Ohio four years later. "The extent to which we were guessing about persuasion was not lost on any of us."

One way the campaign sought to identify the ripest targets was through a series of what the Analyst Institute called "experiment-informed programs," or EIPs, designed to measure how effective different types of messages were at moving public opinion.

The traditional way of doing this had been to audition themes and language in

to ads. They began sending trained volunteers to knock on doors.

focus groups and then test the winning material in polls to see which categories of voters responded positively to each approach. Any insights were distorted by the artificial settings and by the tiny samples of demographic subgroups in traditional polls. "You're making significant resource decisions based on 160 people?" asks Mitch Stewart. "Isn't that nuts? And people have been doing that for decades!"

An experimental program would use those steps to develop a range of prospective messages that could be subjected to empirical testing in the real world. Experimenters would randomly assign voters to receive varied sequences of direct mail—four pieces on the same policy theme, each making a slightly different case for Obama—and then use ongoing survey calls to isolate the attributes of those whose opinions changed as a result.

In March, the campaign used this technique to test various ways of promoting the administration's healthcare policies. One series of mailers described Obama's regulatory reforms; another advised voters that they were now entitled to free regular checkups and ought to schedule one. The experiment revealed how much voter response differed by age, especially among women. Older women thought more highly of the policies when they received reminders about preventive care; younger women liked them more when they were told about contraceptive coverage and new rules that prohibited insurance companies from charging women more.

PERCENTAGE OF VOTES CAST FOR OBAMA BY EARLY VOTERS IN HAMILTON COUNTY, OHIO

57.68%	57.16%
Model	Actual

When Paul Ryan was named to the Republican ticket in August, Obama's advisors rushed out an EIP that compared different lines of attack about Medicare. The results were surprising. "The electorate [had seemed] very inelastic," says Terry Walsh, who coördinated the campaign's polling and paid-media spending. "In fact, when we did the Medicare EIPs, we got positive movement that was very heartening, because it was at a time when we were not seeing a lot of movement in the electorate." But that movement came from quarters where a traditional campaign would never have gone hunting for minds it could change. The Obama team found that voters between 45 and 65 were more likely to change their views about the candidates after hearing Obama's Medicare arguments than those over 65, who were currently eligible for the program.

A similar strategy of targeting an unexpected population emerged from a July EIP testing Obama's messages aimed at women. The voters most responsive to the campaign's arguments about equal-pay measures and women's health, it found, were those whose likelihood of supporting the president was scored at merely 20 and 40 percent. Those scores suggested that they probably shared Republican attitudes; but here was one thing that could pull them to Obama. As a result, when Obama unveiled a direct-mail track addressing only women's issues, it wasn't to shore up interest among core parts of the Democratic coalition, but to reach over for conservatives who were at odds with their party on gender concerns. "The whole goal of the women's track was to pick off votes for Romney," says Walsh. "We were able to persuade people who fell low on candidate support scores if we gave them a specific message."

At the same time, Obama's campaign was pursuing a second, even more audacious adventure in persuasion: one-on-one interaction. Traditionally, campaigns have restricted their persuasion efforts to channels like mass media or direct mail, where they can control presentation, language, and targeting. Sending volunteers to persuade voters would mean forcing them to interact with opponents, or with voters who were undecided because they were alienated from politics on delicate issues like abortion. Campaigns have typically resisted relinquishing control of ground-level interactions with voters to risk such potentially combustible situations; they felt they didn't know enough about their supporters or volunteers. "You can have a negative impact," says Bird. "You can hurt your candidate."

In February, however, Obama volunteers attempted 500,000 conversations with the goal of winning new supporters. Voters who'd been randomly selected from a group identified as persuadable were polled after a phone conversation that began with a volunteer reading from a script. "We definitely find certain people moved more than other people," says Bird. Analysts identified their attributes and made them the core of a persuasion model that predicted, on a scale of 0 to 10, the likelihood that a voter could be pulled in Obama's direction after a single volunteer interaction. The experiment also taught Obama's field department about its volunteers. Those in California, which had always had an exceptionally mature volunteer organization for a non-battleground state, turned out to be especially persuasive: voters called by Californians, no matter what state they were in themselves, were more likely to become Obama supporters.

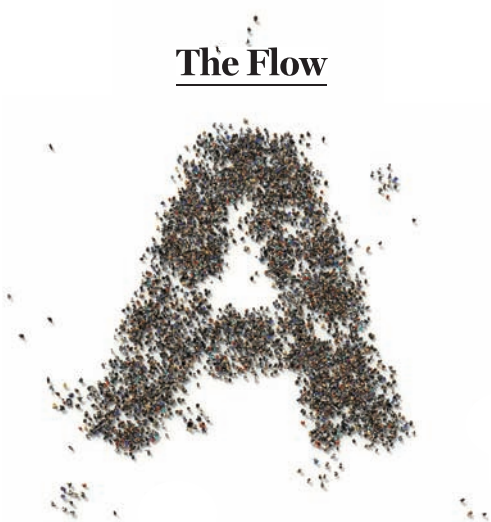
With these findings in hand, Obama's strategists grew confident that they were no longer restricted to advertising as a channel for persuasion. They began sending trained volunteers to knock on doors or make phone calls with the objective of changing minds.

That dramatic shift in the culture of electioneering was felt on the streets, but it was possible only because of advances in analytics. Wegrzyn developed a program code-named Airwolf that matched county and state lists of people who had

requested mail ballots with the campaign's list of e-mail addresses. Likely Obama supporters would get regular reminders from their local field organizers, asking them to return their ballots, and, once they had, a message thanking them and proposing other ways to be involved in the campaign. The local organizer would receive daily lists of the voters on his or her turf who had outstanding ballots so that the campaign could follow up with personal contact by phone or at the doorstep. "It is a fundamental way of tying together the online and offline worlds," says Wagner.

Wagner, however, was turning his attention beyond the field. By June of 2011, he was chief analytics officer for the campaign and had begun making the rounds of the other units at headquarters, from fund-raising to communications, offering to help "solve their problems with data." He imagined the analytics department—now a 54-person staff, housed in a windowless office known as the Cave—as an "in-house consultancy" with other parts of the campaign as its clients. "There's a process of helping people learn about the tools so they can be a participant in the process," he says. "We essentially built products for each of those various departments that were paired up with a massive database we had."

Alex Lundry created Mitt Romney's data science unit. It was less than one-tenth the size of Obama's analytics team.



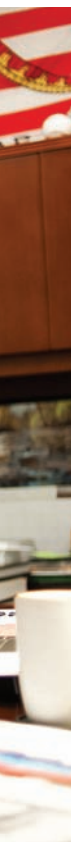
AS JOB NOTICES SEEKING SPECIALISTS IN text analytics, computational advertising, and online experiments came out of the incumbent's campaign, Romney advisors at the Republicans' headquarters in Boston's North End watched with a combination of awe and perplexity. Throughout the primaries, Romney had appeared to be the only Republican running a 21st-century campaign, methodically banking early votes in states like Florida and Ohio before his disorganized opponents could establish operations there.

But the Republican winner's relative sophistication in the primaries belied a poverty of expertise compared with the Obama campaign. Since his first campaign for governor of Massachusetts, in 2002, Romney had relied upon TargetPoint Consulting, a Virginia firm that was then a pioneer in linking information from consumer data warehouses to voter registration records and using it to develop individual-level predictive models. It was TargetPoint's CEO, Alexander Gage, who had coined the term "microtargeting" to describe the process, which he modeled on the corporate world's approach to customer relationship management.

Such techniques had offered George W. Bush's reëlection campaign a significant edge in targeting, but Republicans had done little to institutionalize that advantage in the years since. By 2006, Democrats had not only matched Republicans in adopting commercial marketing techniques; they had moved ahead by integrating methods developed in the social sciences.

Romney's advisors knew that Obama was building innovative internal data analytics departments, but they didn't

Photograph by Daniel Bedell



feel a need to match those activities. "I don't think we thought, relative to the marketplace, we could be the best at data in-house all the time," Romney's digital director, Zac Moffatt, said in July. "Our idea is to find the best firms to work with us." As a result, Romney remained dependent on TargetPoint to develop voter segments, often just once, and then deliver them to the campaign's databases. That was the structure Obama had abandoned after winning the nomination in 2008.

In May a TargetPoint vice president, Alex Lundry, took leave from his post at the firm to assemble a data science unit within Romney's headquarters. To round out his team, Lundry brought in Tom Wood, a University of Chicago postdoctoral student in political science, and Brent McGoldrick, a veteran of Bush's 2004 campaign who had left politics for the consulting firm Financial Dynamics (later FTI Consulting), where he helped financial-services, health-care, and energy companies communicate better.

But Romney's data science team was less than one-tenth the size of Obama's analytics department. Without a large in-house staff to handle the massive national data sets that made it possible to test and track citizens, Romney's data scientists never tried to deepen their understanding of individual behavior. Instead, they fixated on trying to unlock one big, persistent mystery, which Lundry framed this way: "How can we get a sense of whether this advertising is working?"

"You usually get GRPs and tracking polls," he says, referring to the gross ratings points that are the basic unit of measuring television buys. "There's a very large causal leap you have to make from one to the other."

Lundry decided to focus on more manageable ways of measuring what he called the information flow. His team converted topics of political communication into discrete units they called "entities." They initially classified 200 of them, including issues like the auto industry bailout, controversies like the one surrounding federal funding for the solar-power company Solyndra, and catchphrases like "the war on women." When a new concept (such as Obama's offhand remark, during a speech about our common dependence on infrastructure, that "you didn't build that") emerged as part of the election-year lexicon, the analysts added it to the list. They tracked each entity on the National Dialogue Monitor, TargetPoint's system for measuring the frequency and tone with which certain topics are mentioned across all media. TargetPoint also integrated content collected from newspaper websites and closed-caption transcripts of broadcast programs. Lundry's team aimed to examine how every entity fared over time in each of two categories: the informal sphere of social media, especially Twitter, and the journalistic product that campaigns call earned press coverage.

Ultimately, Lundry wanted to assess the impact that each type of public attention had on what mattered most to them: Romney's position in the horse race. He turned to vector autoregression models, which equities traders use to isolate the influence of single variables on market movements. In this case, Lundry's team looked for patterns in the relationship between the National Dialogue Monitor's data and Romney's numbers in Gallup's daily tracking polls. By the end of July, they thought they had identified a three-step process they called "Wood's Triangle."

Within three or four days of a new entity's entry into the conversation, either through paid ads or through the news cycle, it was possible to make a well-informed hypothesis about whether the topic was likely to win media attention by tracking whether it generated Twitter chatter. That informal conversation among political-class elites typically led to traditional print or broadcast press coverage one to two days later, and that, in turn, might have an impact on the horse race. "We saw this process over and over again," says Lundry.

They began to think of ads as a "shock to the system"—a way to either introduce a new topic or restore focus on an area in which elite interest had faded. If an entity didn't gain its own energy—as when the Republicans charged over the summer that the White House had waived the work requirements in the federal welfare rules—Lundry would propose a "reshock to the system" with another ad on the subject five to seven days later. After 12 to 14 days, Lundry found, an entity had moved through the system and exhausted its ability to move public opinion—so he would recommend to the campaign's communications staff that they move on to something new.

Those insights offered campaign officials a theory of information flows, but they provided no guidance in how to allocate campaign resources in order to win the Electoral College. Assuming that Obama had superior ground-level data and analytics, Romney's campaign tried to leverage its rivals' strategy to shape its own; if Democrats thought a state or media market was competitive, maybe that was evidence that Republicans should think so too. "We were necessarily reactive, because we were putting together the plane as it took off," Lundry says. "They had an enormous head start on us."

Romney's political department began holding regular meetings to look at where in the country the Obama campaign was focusing resources like ad dollars and the president's time. The goal was to try to divine the calculations behind those decisions. It was, in essence, the way Microsoft's Bing approached Google: trying to reverse-engineer the market leader's code by studying the visible output. "We watch where the president goes," Dan Centinello, the Romney deputy political director who oversaw the meetings, said over the summer.

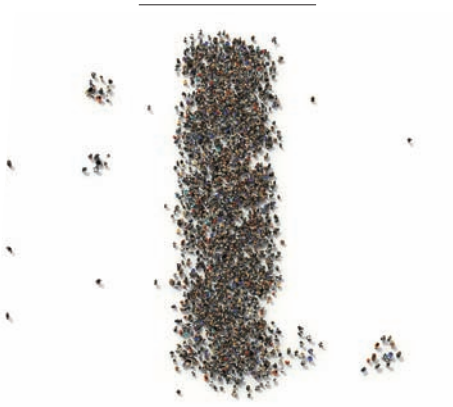
Obama's media-buying strategy proved particularly hard to decipher. In early September, as part of his standard review, Lundry noticed that the week after the Democratic convention, Obama had aired 68 ads in Dothan, Alabama, a town near the Florida border. Dothan was one of the country's smallest media markets, and Alabama one of the safest Republican states. Even though the area was known to savvy ad buyers as one of the places where a media market crosses state lines, Dothan TV stations reached only about

Romney's staff could not decode the Obama team's decisions.

9,000 Florida voters, and around 7,000 of them had voted for John McCain in 2008. "This is a hard-core Republican media market," Lundry says. "It's incredibly tiny. But they were advertising there."

Romney's advisors might have formed a theory about the broader media environment, but whatever was sending Obama hunting for a small pocket of votes was beyond their measurement. "We could tell," says McGoldrick, "that there was something in the algorithms that was telling them what to run."

The March



IN THE SUMMER OF 2011, CAROL DAVIDSEN received a message from Dan Wagner. Already the Obama campaign was known for its relentless e-mails beseeching supporters to give their money or time, but this one offered something that intrigued Davidsen: a job. Wagner had sorted the campaign's list of donors, stretching back to 2008, to find those who described their occupation with terms like "data" and "analytics" and sent them all invitations to apply for work in his new analytics department.

Davidsen was working at Navic Networks, a Microsoft-owned company that wrote code for set-top cable boxes to create a record of a user's DVR or tuner history, when she heeded Wagner's call. One year before Election Day, she started work in the campaign's technology department to serve as product manager for Narwhal. That was the code name, borrowed from a tusked whale, for an ambitious effort to match records from previously unconnected databases so that a user's online interactions with the campaign could be synchronized. With Narwhal, e-mail blasts asking people to volunteer could take their past donation history into consideration, and the algorithms determining how much a supporter would be asked to contribute could be shaped by knowledge about his or her reaction to previous solicitations. This integration enriched a technique, common in website development, that Obama's online fund-raising efforts had used to good effect in 2008: the A/B test, in which users are randomly directed to different versions of a thing and their responses are compared. Now analysts could leverage personal data to identify the attributes of those who responded, and use that knowledge to refine subsequent appeals. "You can cite people's other types of engagement," says Amelia Showalter, Obama's director of digital analytics. "We discovered that there were a lot of things that built goodwill, like signing the president's birthday card or getting a free bumper sticker, that led them to become more engaged with the campaign in other ways."

If online communication had been the aspect of the 2008 campaign subjected to the most rigorous empirical examination—it's easy to randomly assign e-mails in an A/B test and compare click-through rates or donation levels—mass-media strategy was among those that received the least. Television and radio ads had to be purchased by geographic zone, and the available data on who watches which channels or shows, collected by research firms like Nielsen and Scarborough, often included little more than viewer age and gender. That might be good enough to guide buys for Schick or Foot Locker, but it's of limited value for advertisers looking to define audiences in political terms.

As Messina prepared to spend as much as half a billion dollars on mass media for Obama's reëlection, he set out to reinvent the process for allocating resources across broadcast, cable, satellite, and online channels. "If you think about the universe of possible places for an advertiser, it's almost infinite," says Amy Gershkoff, who was hired as the campaign's media-planning director on the strength of her successful negotiations, while at the firm Changing Targets in 2009, to link the information from cable systems to individual microtargeting profiles. "There are tens of millions of opportunities where a campaign can put its next dollar. You have all this great, robust voter data that doesn't fit together with the media data. How you knit that together is a challenge."

TELEVISION COMMERCIALS AIRED ON TV LAND (NATIONAL CABLE LEVEL)

1,710	0
Obama campaign	Romney campaign

By the start of 2012, Wagner had deftly wrested command of media planning into his own department. As he expanded the scope of analytics, he defined his purview as "the study and practice of resource optimization for the purpose of improving programs and earning votes more efficiently." That usually meant calculating, for any campaign activity, the number of votes gained through a given amount of contact at a given cost.

But when it came to buying media, such calculations had been simply impossible, because campaigns were unable to link what they knew about voters to what cable providers knew about their customers. Obama's advisors decided that the data made available in the private sector had long led political advertisers to ask the wrong questions. Walsh says of the

SOURCE: KANTAR MEDIA CMAG

"We were never able to figure out . . . what they were trying to do."

effort to reimagine the media-targeting process: "It was not to get a better understanding of what 35-plus women watch on TV. It was to find out how many of our persuadable voters were watching those dayparts."

Davidsen, whose previous work had left her intimately familiar with the rich data sets held in set-top boxes, understood that a lot of that data was available in the form of tuner and DVR histories collected by cable providers and then aggregated by research firms. For privacy reasons, however, the information was not available at the individual level. "The hardest thing in media buying right now is the lack of information," she says.

Davidsen began negotiating to have research firms repackage their data in a form that would permit the campaign to access the individual histories without violating the cable providers' privacy standards. Under a $350,000 deal she worked out with one company, Rentrak, the campaign provided a list of persuadable voters and their addresses, derived from its microtargeting models, and the company looked for them in the cable providers' billing files. When a record matched, Rentrak would issue it a unique household ID that identified viewing data from a single set-top box but masked any personally identifiable information.

The Obama campaign had created its own television ratings system, a kind of Nielsen in which the only viewers who mattered were those not yet fully committed to a presidential candidate. But Davidsen had to get the information into a practical form by early May, when Obama strategists planned to start running their anti-Romney ads. She oversaw the development of a software platform the Obama staff called the Optimizer, which broke the day into 96 quarter-hour segments and assessed which time slots across 60 channels offered the greatest number of persuadable targets per dollar. (By September, she had unlocked an even richer trove of data: a cable system in Toledo, Ohio, that tracked viewers' tuner histories by the second.) "The revolution of media buying in this campaign," Walsh says, "was to turn what was a broadcast medium into something that looks a lot more like a narrowcast medium."

When the Obama campaign did use television as a mass medium, it was because the Optimizer had concluded it would be a more efficient way of reaching persuadable targets. Sometimes a national cable ad was a better bargain than a large number of local buys in the 66 media markets reaching battleground states. But the occasional national buy also had other benefits. It could boost fund-raising and motivate volunteers in states that weren't essential to Obama's Electoral College arithmetic. And, says Davidsen, "it helps hide some of the strategy of your buying."

Even without that tactic, Obama's buys perplexed the Romney analysts in Boston. They had invested in their own media-intelligence platform, called Centraforce. It used some of the same aggregated data sources that were feeding into the Optimizer, and at times both seemed to send the campaigns to the same unlikely ad blocks—for example, in reruns on TV Land. But there was a lot more to what Lundry called Obama's "highly variable" media strategy. Many of the Democrats' ads were placed in fringe markets, on marginal stations, and at odd times where few political candidates had ever seen value. Romney's data scientists simply could not decode those decisions without the voter models or persuasion experiments that helped Obama pick out individual targets. "We were never able to figure out the level of advertising and what they were trying to do," says McGoldrick. "It wasn't worth reverse-engineering, because what are you going to do?"

ALTHOUGH THE VOTER OPINION TABLES that emerged from the Cave looked a lot like polls, the analysts who produced them were disinclined to call them polls. The campaign had plenty of those, generated by a public-opinion team of eight outside firms, and new arrivals at the Chicago headquarters were shocked by the variegated breadth of the research that arrived on their desks daily. "We believed in combining the qual, which we did more than any campaign ever, with the quant, which we [also] did more than any other campaign, to make sure all communication for every level of the campaign was informed by what they found," says David Simas, the director of opinion research.

Simas considered himself the "air-traffic controller" for such research, which was guided by a series of voter diaries that Obama's team commissioned as it prepared for the reëlection campaign. "We needed to do something almost divorced from politics and get to the way they're seeing their lives," he says. The lead pollster, Joel Benenson, had respondents write about their experiences. The entries frequently used the word "disappointment," which helped explain attitudes toward Obama's administration but also spoke to a broader dissatisfaction with economic conditions. "That became the foundation for our entire research program," says Simas.

Obama's advisors used those diaries to develop messages that contrasted Obama with Romney as a fighter for the middle class. Benenson's national polls tested language to see which affected voters' responses in survey experiments and direct questioning. A quartet of polling firms were assigned specific states and asked to figure out which national themes fit best with local concerns. Eventually, Obama's media advisors created more than 500 ads and tested them before an online sample of viewers selected by focus-group director David Binder.

But the campaign had to play defense, too. When something potentially damaging popped up in the news, like Democratic consultant Hilary Rosen's declaration that Ann Romney had "never worked a day in her life," Simas checked in with the Community, a private online bulletin board populated by 100 undecided voters Binder had recruited. Simas would monitor Community conversations to see which news events penetrated voter consciousness. Sometimes he had Binder show its members controversial material—like a video clip of Obama's "You didn't build that" comment—and ask if it changed their views of the candidate. "For me, it was a very quick way to draw back and determine whether something was a problem or not a problem," says Simas.

When Wagner started packaging his department's research into something that campaign leadership could read like a poll, a pattern became apparent. Obama's numbers in key battleground states were low in the analytic tables, but Romney's were too. There were simply more undecided voters in such states—sometimes nearly twice as many as the traditional pollsters found. A basic methodological distinction explained this discrepancy: microtargeting models required interviewing a lot of unlikely voters to give shape to a profile of what a nonvoter looked like, while pollsters tracking the horse race wanted to screen more rigorously for those likely to cast a ballot. The rivalry between the two units trying to measure public opinion grew intense: the analytic polls were a threat to the pollsters' primacy and, potentially, to their business model. "I spent a lot of time within the campaign explaining to people that the numbers we get from analytics and the numbers we get from external pollsters did not need strictly to be reconciled," says Walsh. "They were different."

Carol Davidsen matched Obama 2012's lists of persuadable voters with cable providers' billing information.

The scope of the analytic research enabled it to pick up movements too small for traditional polls to perceive. As Simas reviewed Wagner's analytic tables in mid-October, he was alarmed to see that what had been a Romney lead of one to two points in Green Bay, Wisconsin, had grown into an advantage of between six and nine. Green Bay was the only media market in the state to experience such a shift, and there was no obvious explanation. But it was hard to discount. Whereas a standard 800-person statewide poll might have reached 100 respondents in the Green Bay area, analytics was placing 5,000 calls in Wisconsin in each five-day cycle—and benefiting from tens of thousands of other field contacts—to produce microtargeting scores. Analytics was talking to as many people in the Green Bay media market as traditional pollsters were talking to across Wisconsin every week. "We could have the confidence level to say, 'This isn't noise,'" says Simas. So the campaign's media buyers aired an ad attacking Romney on outsourcing and beseeched Messina to send former president Bill Clinton and Obama himself to rallies there. (In the end, Romney took the county 50.3 to 48.5 percent.)

For the most part, however, the analytic tables demonstrated how stable the electorate was, and how predictable individual voters could be. Polls from the

media and academic institutions may have fluctuated by the hour, but drawing on hundreds of data points to judge whether someone was a likely voter proved more reliable than using a seven-question battery like Gallup's to do the same. "When you see this Pogo stick happening with the public data—the electorate is just not that volatile," says Stewart. The analytic data offered a source of calm.

Romney's advisors were similarly sanguine, but they were losing. They, too, believed it possible to project the composition of the electorate, relying on a method similar to Gallup's: pollster Neil Newhouse asked respondents how intensely they wanted to cast a ballot. Only those who answered that question favorably were likely to vote, the Republicans believed. But they were wrong. Ignoring the experimental methods that made it possible to measure individual behavior, they failed to see how the Obama campaign was mobilizing even those voters who looked to Election Day without enthusiasm.

On the last day of the race, Wagner and his analytics staff left the Cave and rode the elevator up one floor in the campaign's Chicago skyscraper to join members of other departments in a boiler room established to help track votes as they came in. Already, for over a month, Obama's analysts had been counting ballots from states that allowed citizens to vote early. Each day, the campaign overlaid the lists of early voters released by election authorities with its modeling scores to project how many votes they could claim as their own.

By Election Day, Wagner's analytic tables turned into predictions. Before the polls opened in Ohio, authorities in Hamilton County, the state's third-largest and home to Cincinnati, released the names of 103,508 voters who had cast early ballots over the previous month. Wagner sorted them by microtargeting projections and found that 58,379 had individual support scores over 50.1—that is, the campaign's models predicted that they were more likely than not to have voted for Obama. That amounted to 56.4 percent of the county's votes, or a raw lead of 13,249 votes over Romney. Early ballots were the first to be counted after Ohio's polls closed, and Obama's senior staff gathered around screens in the boiler room to see the initial tally. The numbers settled almost exactly where Wagner had said they would: Obama got 56.6 percent of the votes in Hamilton County. In Florida, he was as close to the mark; Obama's margin was only two-tenths of a percent off. "After those first two numbers, we knew," says Bird. "It was dead-on."

When Obama was reëlected, and by a far larger Electoral College margin than most outsiders had anticipated, his staff was exhilarated but not surprised. The next morning, Mitch Stewart sat in the boiler room, alone, monitoring the lagging votes as they came into Obama's servers from election authorities in Florida, the last state to name a winner. The presidency was no longer at stake; the only thing that still hung in the balance was the accuracy of the analytics department's predictions.

The Legacy

A FEW DAYS AFTER THE ELECTION, AS Florida authorities continued to count provisional ballots, a few staff members were directed, as four years before, to remain in Chicago. Their instructions were to produce another post-mortem report summing up the lessons of the past year and a half. The undertaking was called the Legacy Project, a grandiose title inspired by the idea that the innovations of Obama 2012 should be translated not only to the campaign of the next Democratic candidate for president but also to governance. Obama had succeeded in convincing some citizens that a modest adjustment to their behavior would affect, however marginally, the result of an election. Could he make them feel the same way about Congress?

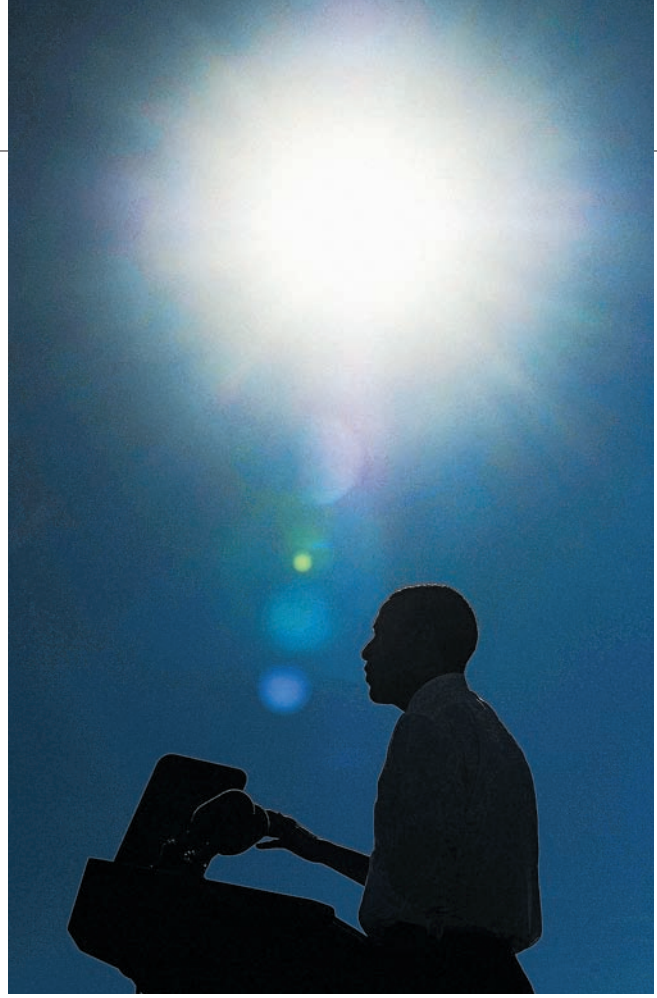
Simas, who had served in the White House before joining the team, marveled at the intimacy of the campaign. Perhaps more than anyone else at headquarters, he appreciated the human aspect of politics. This had been his first presidential election, but before he became a political operative, Simas had been a politician himself, serving on the city council and school board in his hometown of Taunton, Massachusetts. He ran for office by knocking on doors and interacting individually with constituents (or those he hoped would become constituents), trying to track their moods and expectations.

In many respects, analytics had made it possible for the Obama campaign to recapture that style of politics. Though the old guard may have viewed such techniques as a disruptive force in campaigns, they enabled a presidential candidate to view the electorate the way local candidates do: as a collection of people who make up a more perfect union, each of them approachable on his or her terms, their changing levels of support and enthusiasm open to measurement and, thus, to respect. "What that gave us was the ability to run a national presidential campaign the way you'd do a local ward campaign," Simas says. "You know the people on your block. People have relationships with one another, and you leverage them so you know the way they talk about issues, what they're discussing at the coffee shop."

Few events in American life other than a presidential election touch 126 million adults, or even a significant fraction that many, on a single day. Certainly no corporation, no civic institution, and very few government agencies ever do. Obama did so by reducing every American to a series of numbers. Yet those numbers somehow captured the individuality of each voter, and they were not demographic classifications. The scores measured the ability of people to change politics—and to be changed by it. T

Sasha Issenberg is the author of The Victory Lab: The Secret Science of Winning Campaigns.

Photograph by Erika Dufour



In a letter to President Obama, the editors of *MIT Technology Review* argue that addressing climate change must take top priority in the next four years.

DEAR MR. PRESIDENT

Amid the crises and battles, both predictable and unforeseeable, that you will face over the next four years, one problem will stand out both for the economic and social dangers it poses and for the difficulty and cost of solving it. Whether you can develop a practical and sustainable strategy to address climate change—specifically, to begin lowering carbon dioxide emissions—will define the success of your new term as president. We do not make such a declaration lightly; we are keenly aware of the many other challenges you face. But the potential for global warming over the next decades threatens consequences so dire that they could overwhelm any progress you make toward other long-term economic, social, and political goals.

Altering the course of climate change is a task that will take decades. It will require innovative new technologies and overhauls of the world's energy, agricultural, and transportation infrastructure. We don't suggest that you can reverse the warming trend over the next four years, or even that you will be able to significantly decrease carbon dioxide emissions. But with the help of the world's best economic, technical, and scientific minds, you *can* formulate a policy that will show the nation—and the world—how we can begin to make the changes necessary to ensure that the concentration of carbon dioxide in the atmosphere stabilizes at a safe level. Indeed, it is critical that you do so.

Four years ago, you made a remarkable start. The $90 billion in your 2009 stimulus bill for energy projects and research breathed new life into the search for cleaner sources of energy. The appointment of prominent researchers such as Steven Chu, your secretary of energy, and John Holdren, your senior advisor on science and technology, sent a signal that your administration was committed to making decisions based on facts and science. Most important, you made it clear that the government would play a vital role in encouraging the innovation needed to develop these new energy sources.

But you also made several painful mistakes that doomed much of the progress you had hoped for. Perhaps most damaging, you justified much of the spending by holding out the prospect of "green jobs" and suggesting that the creation of a new clean-energy industry could jump-start the economy.

In the May/June 2009 issue of this magazine (see "Can Technology Save the Economy?"), we cautioned against conflating economic stimulus with a sustainable and effective energy policy. Leading economists noted that job creation needed to happen quickly, while transforming our energy infrastructure would take decades. And much of the energy spending in the stimulus bill, suggested one, resembled "pork-barrel politics" to satisfy the immediate need for jobs. The rush to fund energy projects meant that the choices made were not always wise. As another economist warned, "The cost here is not only the dollars. It may also be the dog that doesn't bark—the truly important program that we could put in place if we went about encouraging innovation in a thoughtful way."

Many projects that received large investments in the 2009 stimulus legislation were not (in the term of those days) "shovel-ready"—they were still just promising startups. And yet, because of the emphasis on job creation, hundreds of millions of dollars went into building big manufacturing facilities as quickly as possible. The result set companies like Solyndra, A123 Systems, and Abound Solar on a course that ended in bankruptcy. Each of these companies had interesting technologies, but none was ready for the challenge of building commercial products and selling them in highly competitive energy markets. The outcome, which we foresaw in our 2009 article, was an entirely unnecessary black eye for the clean-energy effort.

Renewable energy sources, like solar and advanced biofuels, are simply not yet ready to compete with fossil fuels. Solar power, for example, still generates less than 1 percent of our nation's electricity and, under most circumstances, remains much more expensive than electricity generated from fossil fuels. We need new and far more advanced technologies. Creating cleaner ways to produce energy will require inventions in physics and chemistry labs *and* innovations in how we scale up and test those inventions. And it will require market incentives, such as a tax or some other price on carbon dioxide emissions, to encourage consumers and industry to use clean energy. Your administration can play a critical role in each of these areas, from increasing funding for energy R&D to helping establish facilities where companies can share the costs and risks of testing new technologies. Perhaps most important, you will need to rally the nation around the issue of tackling climate change. Only with broad public support can you hope to push a recalcitrant Congress into passing legislation that will establish some form of carbon pricing.

Slowing down global warming won't be cheap. You have often stressed the economic benefits of choosing new energy technologies. You make a valid argument that moving away from fossil fuels will have positive implications for many businesses. And certainly new technologies will provide jobs and other economic opportunities. But we can no longer pretend that addressing climate change will be without real costs. Economic studies show that it is likely to cost trillions of dollars worldwide, though those analyses also present evidence that the price will grow higher the longer we wait.

Adding to our difficulties is the recent boom in our country's production of fossil fuels, including natural gas and related deposits of shale oil. Already, the glut of cheap natural gas created by advanced drilling technologies and by the nation's vast supply of shale gas has made it difficult for renewable energy to compete on price. The inexpensive energy made available by these drilling activities is good news for the overall economy, but it is also a stark reminder that the motive for adopting nonfossil fuels is not market-driven but is—and always has been—a simple one: we must do it to reduce carbon dioxide emissions and begin stabilizing our climate.

It's time to acknowledge that green jobs were always just political cover for that motive. You must say unambiguously that the real reason to transform our energy system is to avoid the most catastrophic effects of global warming.

This is a deeply unpalatable political message. It means immediate spending and economic sacrifice by present-day voters in order to achieve benefits that will be realized decades from now. And it must be done while millions of Americans are still skeptical that global warming is taking place or that it is caused by human activity. But as extensive and exacting analyses over the last decade have shown, we can no longer wait without risking dramatic upheavals in global security and the health and welfare of hundreds of millions of the world's inhabitants.

The International Energy Agency reports that global emissions of carbon dioxide from fossil-fuel combustion reached a record 31.6 metric gigatons in 2011. To have a decent chance of limiting the average global temperature increase to 2 °C and avoiding the most devastating effects of climate change, we will need carbon emissions to peak at no more than 32.6 metric gigatons, and to start falling no later than 2017. The president who takes office that year will thus be facing a far more urgent problem—probably, like you, with no political consensus on how to solve it. But as a president in his final term, you have a chance to take risks. You have the power and the opportunity to lay the groundwork for a new clean-energy policy that will help us avoid the worst consequences of climate change. It is quite possible that if this is not done over the next four years, it will be too late. T

OPPOSITE: JEWEL SAMAD/AFP/GETTY IMAGES

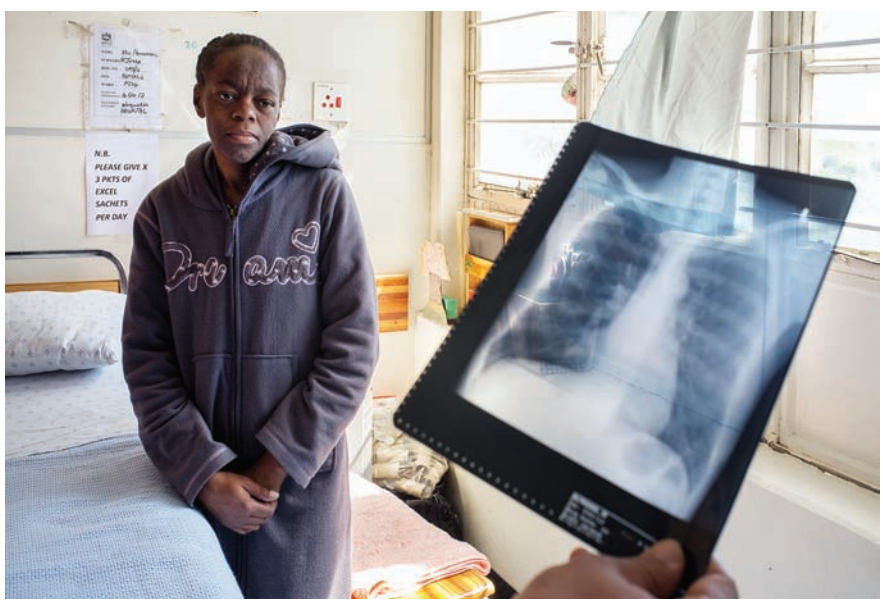
Nearly 1.5 million people die from tuberculosis every year, even though most cases can be cured with routine antibiotic treatments. One country's fight to get the ancient scourge under control has an unlikely hero: a simple diagnostic test.

By Jon Cohen
Photographs by Malcolm Linton

TB bacteria in a GeneXpert cartridge (blue, foreground) can be detected in under two hours. Sputum samples (purple and green caps) take weeks to culture.

The Machine That Will Help End TB

KwaMsane Township sits amid rolling hills in South Africa's KwaZulu-Natal Province. Drive 30 minutes to the west and elephants, giraffes, zebras, and rhinos often stroll by the side of a highway that cuts through a game park. A few kilometers to the east lie sprawling sugarcane fields, which shimmer in the subtropical sun and appear to spill into the Indian Ocean. KwaMsane is beautiful, but it has one of the world's highest rates of multidrug-resistant (MDR) tuberculosis, an often fatal form of the disease.



Nomthandzau Elizabeth Mjwara has a case of drug-resistant TB that went undiagnosed for months.

In November 2011, Jabu Ngcobo, 25, felt a pain in her side and went to the KwaMsane clinic, which resembles a trailer park. The clinic's trailers—called parkhomes here—surround a small covered courtyard that serves as a waiting room, with patients sitting in plastic chairs. "I was all along thinking I had MDR TB because my two brothers and my sister had it," says Ngcobo.

Her siblings learned they had the dangerous form of the disease only after giving sputum samples, which had to be transported to a laboratory in Durban, 275 kilometers to the south. The lab then had to nurture cultures of *Mycobacterium tuberculosis* until the colonies were large enough to be subjected to drug susceptibility tests. At best, the process takes six weeks; in reality, given the need to transport the samples, the likelihood of lab backlogs, and delays in reporting the results, three months often pass before patients in rural towns like KwaMsane learn whether they will benefit from a relatively simple, six-month course of antibiotics or instead need an 18-month barrage of heavy-duty drugs. The delay can mean the difference between permanent lung damage, or even death, and recovering with no long-term consequences.

WHY IT MATTERS

Tuberculosis is one of the leading causes of death in much of the world; HIV is the only infectious disease that kills more people. Yet many TB cases go undiagnosed.

Ngcobo indeed had the drug-resistant form of TB—and she began treatment the next day. Richard Lessells, a Scottish physician who treated her and her family members at KwaMsane clinic, notes that for Ngcobo's siblings, the months that passed without proper treatment came at a steep cost: one of her brothers suffered lung damage that will never heal. Jabu, in contrast, had no detectable levels of the bacteria a month after diagnosis, because she immediately started taking 22 pills a day as well as injections of anti-TB drugs.

Ngcobo's speedy diagnosis and recovery were made possible by a machine called a GeneXpert, which sits atop a counter inside one of the trailers and resembles a high-end espresso maker. Although the advanced molecular tricks it uses to identify the DNA of *M. tuberculosis* would have been unimaginable outside a state-of-the-art biology lab a few years ago, the device is simple to use. A technician squirts a sputum sample from a patient into what looks like a printer cartridge and then clicks that into the machine, which performs a reaction that amplifies specific bits of *M. tuberculosis* DNA if they are present. Fluorescent molecules light up when they come in contact with the targeted DNA, and the machine detects the fluorescence, sending the information to a computer. The entire process takes a mere two hours. Not only can GeneXpert detect the presence of the TB-causing bacteria, but it can accurately determine whether the bacterial DNA has the mutations known to make the disease resistant to the most commonly used drug.

Tuberculosis, which routinely spreads through the air, infects one-third of the

Durban TB doctor Iqbal Master welcomes the GeneXpert but says it creates many challenges.

human population. For almost all of those people it's harmless, and most don't even know they have been infected. And for much of the world, it is a disease mainly of historical significance. But in many poor countries, particularly in much of central and southern Africa, it remains at epidemic proportions. In 2011, an estimated 8.7 million people became sick from *M. tuberculosis*. Roughly 1.4 million people die of TB each year; HIV is the only infectious agent that kills more.

One critical reason this epidemic continues is that there's no effective and affordable way to tell who is infected. TB goes undiagnosed in some three million people each year. Some simply are never tested. Others, because of antiquated diagnostic technologies, are wrongly given a clean bill of health. Traditional diagnosis for TB relies on staining a sputum sample with dyes and then examining a slide under a microscope to look for the bacteria. This "smear" test, developed 125 years ago, detects fewer than 60 percent of all cases and doesn't identify drug-resistant strains. The more precise culture test to determine sensitivity to certain drugs takes longer, costs more, and needs to be done in a well-equipped lab—so it is used sparingly. That means roughly 80 percent of the drug-resistant cases in the world go undetected, according to the World Health Organization. Together, these undiagnosed individuals represent a vast reservoir for the bacteria, including drug-resistant strains. Infection flourishes and leapfrogs through communities, devastating the most vulnerable people, such as those already weakened by HIV.

A practical, quick, and powerful diagnostic tool could change that deadly dynamic. Brought to market by a public-private partnership between the University of Medicine and Dentistry of New Jersey, the Foundation for Innovative New Diagnostics in Geneva, Switzerland, and Cepheid, a manufacturer based in Sunnyvale, California, the GeneXpert TB detection machine gained approval from the WHO in December 2010. A few months later, South Africa's health minister, Aaron Motsoaledi, compared the machines to "bazookas" in the war against TB and pledged to place them in each of the country's 52 districts.

The GeneXpert machine alone will not be enough to break the back of the massive TB problem in South Africa or anywhere else. That would probably take a powerful vaccine combined with much more potent drugs than now exist. But meanwhile, for countries walloped by TB, including increasing numbers of cases resistant to increasing numbers of drugs, such a diagnostic tool is a crucial and necessary first step. Deploying it widely throughout a country like South Africa, where much of the population lacks access to advanced medical care, will be a logistical and financial challenge. But failing to do so could be deadly. To understand the stakes, it is worth considering the out-

A patient with drug-resistant TB receives his painful daily injection at King George V Hospital.

break a few years ago of a nightmare TB strain just a few hundred kilometers from KwaMsane Township.

DREAMS

One of the most frightening aspects of TB is that humans have treated it with such indifference. All too often, patients start treatment, soon feel better, and then stop taking their pills or take them only sporadically. This creates a perfect opportunity for resistance to develop, because the bacteria with mutations that make them least susceptible to the drug will be likely to survive the incomplete treatment. Then there is the scariest scenario of all: inappropriately diagnosed or incompletely treated MDR TB can foster "extensively" drug-resistant (XDR) mutants that dodge two of the main classes of TB drugs. An outbreak of just such a strain was reported for the first time in 2006. And it took place in KwaZulu-Natal.

Tugela Ferry, about a four-hour drive from KwaMsane Township, is a small town in the central part of the province. In August 2006, headlines around the world described the startling news that 52 of 53 TB patients who had checked into the Church of Scotland Hospital there had died—on average, within 16 days of admission. Tests later revealed that they had XDR strains. The outbreak forced South Africa to look long and hard at the public-health failures that had allowed these dangerous strains to evolve and spread. Front and center was the lack of appropriate diagnostic tools. Given that even under ideal circumstances it would take more than a month to diagnose drug-resistant TB, the patients had no chance: all died before they ever learned they had a deadly form of the disease.

In the wake of Tugela Ferry, the government designated wards at King George V Hospital, a 75-year-old TB facility in Durban, solely for drug-resistant cases. The goal was both to improve treatment outcomes and to slow the spread of the disease. The hospital has seven wards with 32 beds each, including one devoted exclusively to children. There's a waiting list to get in, although Iqbal Master, the doctor who manages the program, is proud that all sick patients, and those with XDR TB, are now admitted within a few weeks of being referred; in January 2007, delays ran to four months. "We had patients dying while on a waiting list," he says.

Patients like Nomthandzau Elizabeth Mjwara, a 48-year-old woman who has HIV and MDR TB, are grateful to secure one of the 224 beds. "It's like I'm staying at my home," says Mjwara, who has lived in the hospital since April. After she fell seriously ill, four months passed before she sought care, gave a sputum sample, received her TB diagnosis, and was admitted to King George V to begin treatment. Many HIV-infected patients arrive at the hospital at such an advanced stage of AIDS that even the proper TB treatment is too little, too late. Fortunately, despite the diagnostic delays, Mjwara still had enough of an immune system left to respond to the drugs.

Despite the upbeat attitude of patients like Mjwara and the first-rate care they receive, many at King George V suffer from advanced cases of TB, and many

Technician Gregory Mkhize shows off the largest GeneXpert machine in Africa, at Prince Mshiyeni Memorial Hospital. It can process 48 samples at once.

leave in coffins. The ones who survive, like Mjwara, have to endure several months of painful daily injections that can cause hearing loss and psychosis. Coughs punctuate the wards day and night, and to discourage airborne infection, windows stay open even when the temperature drops.

Almost everything positive that's said about tuberculosis is followed by a "but."

Most of the doctors and nurses who work the ward wear face masks. Master pointedly does not, in part because the patients with hearing loss rely heavily on reading lips. He has a sympathetic and wistful smile, accented by a wise man's bushy salt-and-pepper beard. "The beard protects me from TB," Master jokes.

If GeneXpert is used effectively in South Africa, it will ultimately ease pressures on hospitals like King George V, slowing the spread of resistant cases by speeding their detection and starting people on the proper treatment earlier. However, almost everything positive that's said about TB is followed by a "but," and Master is quick to stress the limitations of the technology. One is technical. Culture tests remain more accurate than GeneXpert. What's more, testing of cultures remains the only way to accurately diagnose XDR TB. Finally, the aggressive drive to start using GeneXpert countrywide is taxing the health-care system. While identifying those with the active disease will provide a long-term public-health benefit, it will increase the immediate number of patients seeking medical care. Master cites studies suggesting that GeneXpert will increase the patient load by up to 500 percent in the short term. "They haven't sorted out the logistics of what's the ideal way to roll out GeneXpert," he says. "It's going to take time."

On a brisk September morning, Master stops by Mjwara's bed and admires one of her many craft projects, a desktop pencil holder she fashioned from empty toilet paper rolls and tongue depressors. "So that's where my tongue depressors went!" he teases. Her sweatshirt has a word stitched across it: "Dreams."

WAITING FOR A VACCINE

Although many parts of South Africa are wealthy, Durban's Prince Mshiyeni Memorial Hospital is a reminder that much of the country is still extremely poor and lacks modern medical facilities. The 1,200-bed hospital has guards at its entrance, narrow halls filled with sickly patients, and crowds of people constantly moving down the corridors. Durban doctors who do not work there often roll their eyes at the mention of its name, and recent news stories recount problems with a shortage of staff, long lines at the dispensary, security lapses (including a missing dead body), and an outbreak of bacterial infection that killed five babies. But on the grounds of this sprawling hospital is the largest GeneXpert machine in Africa. Unveiled by Health Minister Motsoaledi on World TB Day in March 2011, the

mammoth machine is two meters tall and 2.5 meters long. It can process 48 cartridges at a time; they move through the contraption by means of conveyor belts and a robotic arm.

A few years ago Motsoaledi helped lead a successful countrywide campaign to test 15 million people for HIV and administer retroviral drugs to everyone with a severely damaged immune system. Now he's optimistic that GeneXpert, which he vowed would be in every public facility in South Africa that needed one by the end of 2012, will "revolutionize" the control of tuberculosis. "When we launched the campaign [to test for HIV] in 2010, there was no GeneXpert, so the TB screening was done with five questions," Motsoaledi says. "Just asking five questions and deciding on the basis of your answers?" he asks incredulously. "Now in most of the testing stations we make sure that GeneXpert is there."

The costs of the diagnostic machines are dwarfed by the expense of providing months of hospital care for TB patients.

But merely having the machines isn't enough. On one weekday in September, the 48-cartridge machine at Prince Mshiyeni Memorial Hospital was running only one sample. That's because the rapid scale-up of advanced TB testing has stressed the system to the buckling point. Only one supplier provides cartridges, and there already have been shortages, leading to a "huge backlog of unprocessed specimens," says Stephen Carpenter, clinical manager of the Don McKenzie Hospital in Botha Hills, outside Durban. GeneXpert had yet to reach his own hospital. "We were promised that it would be rolled out all over the province and the district, but there have been all sorts of financial and logistical delays," he says.

Indeed, deploying GeneXpert requires a significant investment by South Africa's government. A four-cartridge machine with a desktop computer sells for $17,000, and cartridges go for $9.98. Analyses show that a GeneXpert test in South Africa, including staff time and machine maintenance, costs roughly $25 per sample, versus $3 for a sputum smear and $12 to $16 for a culture. The increased cost is offset to a degree by the fact that GeneXpert incorporates resistance testing—traditional drug sensitivity testing for first-line treatments costs $72 per test—but all told, a paper published by *PLOS ONE*

Because GeneXpert doesn't require culturing TB, it reduces risks to lab workers.

Jabu Ngcobo developed drug-resistant TB but was quickly diagnosed with GeneXpert and recovered fully.

found, South Africa will have to spend 55 percent more per suspected TB case if it fully scales up the use of the technology as planned.

The flip side is that the country will receive serious bang for its rand, because the costs of the machine are dwarfed by the expense of providing months of hospital care for TB patients. "The diagnosis costs are a very, very small fraction of the total TB control program, and there's substantial benefit," says Mark Nicol, a clinical microbiologist who has a joint appointment at the University of Cape Town and the government's National Health Laboratory Service. Nicol notes that poorer countries with high TB burdens will need outside help. "But it's a price that South Africa certainly can afford," he says.

He is not alone in considering the test worthwhile. "GeneXpert has transformed the way we diagnose TB," says Nesri Padayatchi, who previously managed the TB wards at King George V and now works across town on TB and HIV at the Centre for the AIDS Programme of Research in South Africa. But here comes the inevitable "but": "You can identify all these patients, but it's not addressing the central problem." TB clinicians like Padayatchi have long dreamed of better medicines to both prevent and treat the disease. A TB vaccine was actually introduced nearly a century ago and is widely used. But so much controversy surrounds its efficacy that the United States, for one, does not generally recommend it. "It's a wonder vaccine—you wonder whether it works," jokes Padayatchi. Eleven TB vaccines are currently in clinical trials, a reflection of the intense efforts over the past decade to rejuvenate the field, but none has yet warranted a full-scale efficacy study. The World Health Organization estimates that the earliest a vaccine could be licensed is 2020.

As for treatments, no new class of TB drugs has come to market in 40 years, though two are expected to finish human testing this year; each appears to work against resistant strains. Nine other compounds are at various stages of human studies. Still, the future of these drugs remains uncertain.

International health agencies have agreed on a plan to reduce TB to less than one case per million people by 2050. That would be a drop from 8.7 million cases globally today to roughly 7,000. The partnership specifies that the key to success is an effective vaccine combined with treatments capable of defeating drug-susceptible *M. tuberculosis* within two months. There is no guarantee, of course, that either of those will be developed by 2050. But GeneXpert can at least move the world closer to the goal of nearly eliminating this disease.

Jon Cohen is a correspondent for Science *and a freelance writer; his books include* Shots in the Dark: The Wayward Search for an AIDS Vaccine. *He has covered the HIV/AIDS epidemic in Africa and elsewhere since the early 1990s.*

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A BUSINESS REPORT ON

Digital Education

The highest ambition of any society is to educate its citizens. Now, technologies that extend free learning to everyone, everywhere, are disrupting the business model of education.

CONTENTS

Read all 12 stories in this report at technologyreview.com/business

Additional stories include "Tablet Makers Pursue Public Schools," "The Education Giant Adapts," "The New Internet Teaching Stars," and more.

GOLDEN COSMOS

The Big Question

The Most Important Education Technology in 200 Years

Students everywhere are being offered free instruction online. What will that do to the trillion-dollar education business?

● If you were asked to name the most important innovation in transportation over the last 200 years, you might say the combustion engine, air travel, or Henry Ford's Model-T production line. The list goes on.

Now answer this one: what's been the single biggest innovation in education?

Don't worry if you come up blank. You're supposed to. The question is a gambit used by Anant Agarwal, the computer scientist named this year to head edX, a $60 million MIT-Harvard effort to stream a college education over the Web, free, to anyone who wants one. His →

point: it's rare to see major technological advances in how people learn.

Agarwal believes that education is about to change dramatically. The reason is the power of the Web and its associated data-crunching technologies. It's now possible to stream video classes with sophisticated interactive elements, and researchers can scoop up student data that could help them make teaching more effective. The technology is powerful, fairly cheap, and global in its reach. EdX has said it hopes to teach a billion students.

Online education isn't new—in the United States more than 700,000 students study in full-time "distance learning" programs. What's different is the scale of technology being applied by leaders who mix high-minded goals with sharp-elbowed, low-priced Internet business models. In this business report, here and online, *MIT Technology Review* charts the impact of free online education, particularly the massive open online courses, or MOOCs, offered by new education ventures like edX, Coursera, and Udacity, to name the most prominent.

These ideas affect large markets. Just consider that a quarter of the American population, 80 million people, is enrolled in K–12 education, college, or graduate school. Direct expenditures by government exceed $800 billion. Add to that figure private education and corporate training.

Because education is economically important yet appears inefficient and static with respect to technology, it's often cited (along with health care) as the next industry ripe for a major "disruption." This belief has been promoted by Clayton Christensen, the influential Harvard Business School professor who coined the term "disruptive technology." His two books on education lay out a blueprint for online learning: it will continue to spread and get better, and eventually it will topple many ideas about how we teach—and some institutions as well.

In Christensen's view, disruptive innovations find success initially in markets "where the alternative is nothing." This can account for why online learning is already important in the adult-education market (think low-end MBAs and nursing degrees). It also explains the sudden rise of organizations such as Khan Academy, the nonprofit whose free online math videos have won funding from Bill Gates and adulation from the media. Khan gained its first foothold among parents who couldn't afford $125 an hour for a private math tutor. For them, Salman Khan, the charming narrator of the videos, was a plausible substitute.

Khan's simple videos aren't without their critics, who wonder whether his tutorials really teach math so well. "We agree 100 percent we aren't going to solve education's problems," Khan responds. But he says the point to keep in mind is that technologywise, "we're in the top of the first inning." He's pouring $10 million a year into making his videos better—already there are embedded exercises and analytics that let teachers track 50 students. Pretty soon, Khan says, his free stuff "will be as good or better than anything anyone is charging money for."

Digital instruction faces limits. Online, you will never smell a burning resistor or get your hands wet in a biology lab. Yet the economics of distributing instruction over the Web are so favorable that they seem to threaten anyone building a campus or hiring teachers. At edX, Agarwal says, the same three-person team of a professor plus assistants that teaches analog circuit design to 400 MIT students now handles 10,000 online and could take 1,000,000.

The rise of the MOOCs also means we can begin thinking about how free, top-quality education could change the world. Khan's videos are popular in India, and the MOOC purveyors have found that 60 percent of their sign-ups are self-starters from knowledge-hungry nations like Brazil and China. Nobody knows what a liberal application of high-octane educational propellant might do. Will it supersize innovation globally by knocking away barriers to good instruction? Will frightened governments censor teachers as they have the Web?

80 million

Number of full-time students in the U.S.

$800 billion

Annual government expenditures on education in the U.S.

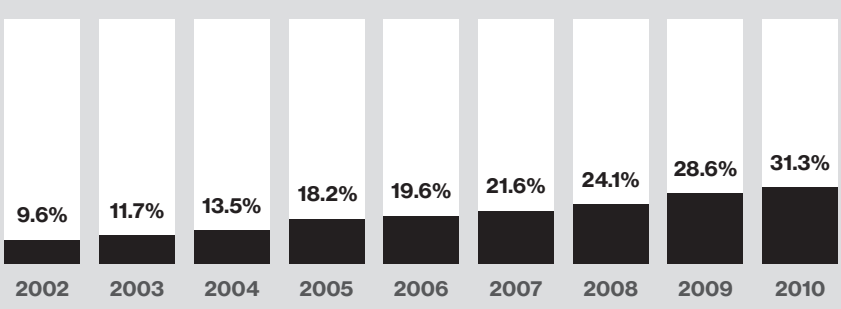
Technology will define what happens next. All those millions of students clicking online can have their progress tracked, logged, studied, and probably influenced, too. Talk to Khan or anyone behind the MOOCs (which sprang largely from university departments interested in computer intelligence) and they'll all say their eventual goal isn't to stream videos but to perfect education through the scientific use of data. Just imagine, they say, software that maps an individual's knowledge and offers a lesson plan unique to him or her.

Will they succeed and create something truly different? If they do, we'll have the answer to our question: online learning will be the most important innovation in education in the last 200 years.

— Antonio Regalado

Education Gets Disrupted, Gradually

Percentage of U.S. college students enrolled in at least one online course



SOURCE: BABSON SURVEY RESEARCH GROUP

Leaders

The Technology of Massive Open Online Courses

Experts in artificial intelligence are bringing online learning to the world.

Artificial-intelligence researchers Andrew Ng and Daphne Koller left academia to start an online-education company.

JEFF CHIU/ASSOCIATED PRESS

● The wave of enthusiasm for online education is unearthing some hard and interesting computational problems that Daphne Koller would love to solve. But first she has to find the time.

Last January, Koller and her colleague Andrew Ng took leave from faculty positions at Stanford University's artificial-intelligence lab to create Coursera, a venture-financed online-education startup with offices near campus.

Since then, Coursera's growth has been rapid and all consuming. The company has posted more than 200 free classes taught by professors at 33 top universities, such as the University of Pennsylvania and Caltech. More than 1.5 million students have signed up, and about 70,000 new students—the equivalent of four or five Stanfords—join every week.

Koller, 44, now spends her average day "probably on a plane somewhere" headed to pitch Coursera to university administrators. The last 10 months have transformed her from a celebrated expert in statistics into the co-CEO of a large and complex educational website whose moneymaking plans are still nascent.

"As I drive home, I sometimes think this is somebody else's life," she says. She calls the experience "surreal."

So far, tearing down the paywalls around higher education has been the simple part. What's more challenging is making online classes like "A History of the World Since 1300" and "Algorithms I" match the quality of their in-person equivalents. That means racing to set up live forums for class discussions, keeping the site from crashing under the crush of students, and urgently seeking ways to make classes more interactive.

Given such technical challenges, it's not an accident that many of the people behind recent efforts to put college courses online come from computer science labs. Another researcher, Sebastian Thrun, resigned from Stanford to create the startup Udacity. At MIT, the former head of the AI department now runs edX, another of the organizations offering massive open online courses, or MOOCs.

"We saw the opportunity and the technology and had the ability to leverage it," says Koller. But putting classes online is only part of what the AI researchers intend. By following the progress of millions of students online, it may be possible to develop insights into how people learn and tailor classes on an individual level. "What we have here is an unprecedented level of detail and scale of data," she says.

Koller, a third-generation PhD who grew up in Jerusalem, is no stranger to new forms of teaching: more than a decade ago, Stanford began broadcasting one of her classes for adult-education students. Eventually, Koller began telling all her students to watch the lectures at home. "All of a sudden, the idea kind of just popped into my brain that it didn't make sense for me to [give] the same lecture that I've been teaching for 15 years, the same jokes at the same time," she says.

In 2011, she and Ng helped Stanford open three classes online to the public at large. This year, they raised $22 million from investors to start Coursera and create a Web platform any school could use. Like its technology, Coursera's business model is a work in progress. One idea considered has been a job board to connect employers to students. Another is to charge students who want to earn an official credit. In November, Antioch University in Los Angeles said it would begin letting students take two Coursera classes for credit, splitting the modest revenues with the company.

"We saw the opportunity and the technology and had the ability to leverage it," says Daphne Koller.

Classes on the site are still of uneven quality. Some are little more than a video of a talking professor. But Koller believes this is just the beginning. By collecting an unprecedented amount of data about how students are learning, and analyzing it in real time, educators could realize their dreams of personalized education →

at a large scale. "The goal is to design personalization, and to identify where someone is struggling and what might be helpful to them," she says.

Some of Koller's own academic research published this February illustrates how this might work. She and several collaborators applied machine-learning techniques to study an introductory programming class. The researchers created mathematical descriptions of the students themselves, looking for models that would explain their advances and setbacks. One discovery: success in the course was predicted by a student's approach to solving the first assignments, not by right or wrong answers.

Automation becomes more difficult—yet also more important—the further Koller gets from her familiar ground of math and computer science. Multiple-choice questions, computer code, and math problems can be graded by a machine. But what about an essay, a drawing, or a question whose correct answer could be "Obama" or "the president"?

These are still hard problems for computer science. For its liberal-arts classes, Coursera has instead devised a peer grading system, in which a computer assigns classmates to give one another feedback. One popular class that uses this system is "Modern & Contemporary American Poetry," taught by University of Pennsylvania professor Al Filreis. It consists of a lively discussion, organized much like a call-in show, with questions taken from the phones and Twitter.

Around 30,000 students signed up—making one-on-one teaching impossible. From the class discussion forums, it's clear not everyone is thrilled with the peer grading approach. In another Coursera class, confusion caused delays and midcourse changes to the grading system.

Despite such glitches, Koller's conversations with potential university partners are becoming easier. Online learning used to be synonymous with shady diploma mills that offered a questionable product. Now it suggests something much better and more technologically sophisticated. "There's been a huge transition in people's thinking," she says. —*Jessica Leber*

Case Studies

Online Courses Put Pressure on Universities in Poorer Nations

A professor in El Salvador challenges his school by becoming an advocate for massive open online courses.

● When prominent U.S. universities began offering free college classes over the Web this year, more than half the students who signed up were from outside the United States. One of them was Carlos Martinez, a professor of electrical engineering at the University of El Salvador.

Last spring, Martinez enrolled in a class on electronic circuits offered by edX, the $60 million collaboration between MIT and Harvard designed to stream massive open online courses, or MOOCs, over the Web. He thought it was so good that he began traveling around El Salvador to convince others to join the class and launched a blog in English to document his adventures as his country's first "MOOC advocate."

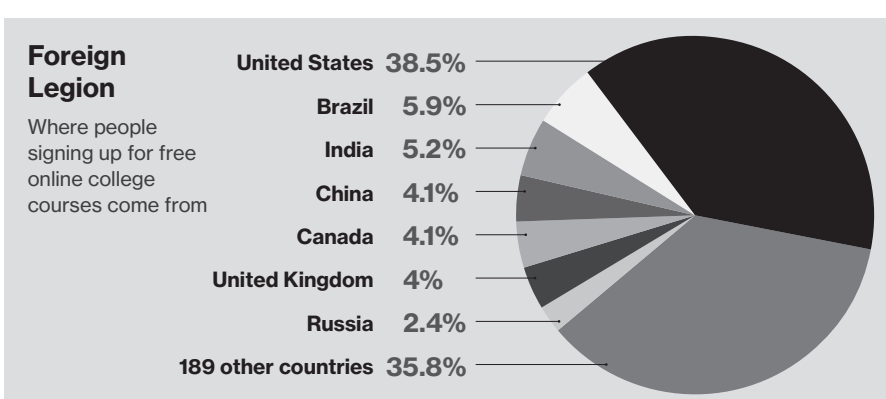
It's an adventure because Martinez doesn't have the backing of his university. This fall, on his own initiative, he signed up 50 students—about one-tenth of the electrical-engineering majors at his school—to take the edX circuits class. Since he's not assigned to teach this subject, he communicates with the students on Facebook, and once a week he sets up an experiment in a hallway to accompany the class. "I'm like a carnival barker," Martinez says. "It's all very chaotic. There's no obligation. No grade. It's 'How are you, don't give up, can I help you?'"

In fact, he's more or less thrown down the gauntlet before a system he says is antiquated and out of touch with technology. "I want to let the new ideas in, raise the bar, and change the curriculum," says Martinez, who has taught at the school since 1994.

The University of El Salvador, located in San Salvador, is the only public university in the country. It spends $60 million a year to teach 50,000 students and can accept only about one-third of those who want to attend. (By comparison, the University of Michigan spends $1.6 billion on its core academic mission, not including sports teams, dorms, and hospitals.) Protests over the shortage of spots regularly shut down the campus. Semesters don't end on time. The university doesn't appear in international rankings.

Martinez says the arrival of MOOCs is adding to an already "huge pressure" to improve the university. And early data on the new Web classes suggest they may have similar impacts elsewhere. Coursera, the largest MOOC company, reported in August that of its first million users, 62 percent were from outside the U.S., led by students in Brazil, India, and China.

So far, students are coalescing around such classes in ways that are improvised



and ad hoc. Some are using online bulletin boards to arrange study groups at cafés in cities like Shanghai and Madrid. "We do hope that people grab these classes and build on them," says Anant Agarwal, the head of edX and the teacher whose voice is heard narrating the electronics class. He even imagines overseas "educational dormitories" springing up, where some entrepreneur might charge for food and a bed and perhaps supply a teaching assistant to help with classwork.

In several cases, enterprising teachers have taken the lead. A U.S. graduate student, Tony Hyun Kim, used edX last spring to teach high-school students in Ulan Bator, the capital of Mongolia. A dozen passed the course. After hearing about it, the National University of Mongolia sent several deans on a mission to visit Agarwal at edX's offices in Cambridge, Massachusetts.

While MOOCs could be an opportunity to improve education in poor regions, they're also profoundly threatening to bad professors and to weak institutions. Sebastian Thrun, the Google researcher who also runs educational startup Udacity, has predicted that within 50 years there might be only 10 universities still "delivering" higher education.

That worries some people. Jason Lane and Kevin Kinser, two education studies professors, warned in the *Chronicle of Higher Education* of an impending "McDonaldization" of college classes: the exact same stuff served everywhere.

Martinez, who teaches wireless communications and Internet telephony, doesn't see things that way. During the last 20 years, he says, his university's electrical-engineering classes have "developed a very bad reputation." Students get stuck and professors don't help. Only 7 percent of incoming majors ever graduate, and those who do get a degree take an average of nine years, about twice as long as they should.

One problem is out-of-date coursework. Martinez says computer science is still taught using the waterfall model, a programming approach that dates to the punch-card era. "A computer science student here spends the first six months doing flow diagrams, because that's how we did it in the 1970s in El Salvador when we didn't have any computers to work on," he says. MOOCs, by contrast, are teaching a new technique known as agile software development in classes like edX's CS169.1, which focuses on how Web-based programs such as Gmail are created.

$60 million

The budget the University of El Salvador has to teach 50,000 students

>$1.6 billion

How much the University of Michigan spends to teach 43,000 students

Martinez has been buttonholing other professors and trying to get them to sign up for a MOOC too. So far, he says, the reception to his ideas from fellow teachers has been "very chilly, very distant."

"I'm trying to tell them the world has evolved and you have to do something in a different way," says Martinez. "The youngest professors can face the change. The older ones, I think it's impossible."

—Antonio Regalado

Case Studies

Free Textbooks Spell Disruption for College Publishers

Startup companies offering knockoff textbooks are attracting students, and lawsuits.

● Ask Ariel Diaz why he's taking on the college textbook industry and he'll tell you, "Quaternions."

Quaternions are a number system used for calculating three-dimensional motion, popular in computer graphics. And Diaz needed a crash course to help him with a consulting gig after his online video platform startup, Youcastr, had failed. He started with Wikipedia and found it was surprisingly good at explaining this complicated mathematics.

Diaz, who still resents how much he paid for textbooks in college, realized he'd hit on his next business idea. In 2011, he started Boundless Learning, a Boston company that has begun giving away free electronic textbooks covering college subjects like American history, anatomy and physiology, economics, and psychology.

What's controversial is how Boundless creates these texts. The company trawls for public material on sites like Wikipedia and then crafts it into online books whose chapters track closely to those of top-selling college titles. In April, Boundless was sued by several large publishers who accused the startup of engaging in "the business model of theft."

Theft or not, the textbook industry is ripe for a disruptive shock from the Internet. Publishers today operate using what Mark Perry, a professor at the University of Michigan, calls a "cartel-style" model: students are required to buy specific texts at high prices. Perry has calculated that textbook prices have risen at three times the rate of inflation since the 1980s.

On average, college students spend around $1,200 each year on books and supplies. Those costs, which sometimes exceed the tuition at a community college, are prompting a wider rebellion against commercial publishers. In February, California legislators passed a law directing the state to produce free versions of texts used in the state's 50 most popular college courses. In October, Secretary of Education Arne Duncan said printed textbooks, a $6 billion industry in the United States (when sales of both used and new books are tallied), should be made "obsolete."

Unlike publishers, who market to professors, Diaz's company is aiming directly at students. Starting in the summer of 2011, Boundless handed out flyers on four campuses, including Florida State →

University. Within weeks, Diaz says, students from 1,000 campuses had signed up.

In their lawsuit, filed in March, publishers Cengage Learning, Pearson Education, and MacMillan Higher Education accused Boundless of copyright infringement, false advertising, and unfair competition. Diaz denies all the charges. He says his company uses only public information and doesn't actually make or sell textbooks. "We see it as how do you create the next-generation content platform, which is much more than a textbook," he says.

For now, however, replacing textbooks like N. Gregory Mankiw's *Principles of Economics* (which retails for $294 new) or Campbell and Reece's *Biology* ($208) does appear to be Boundless's primary activity. When students type in the name of either text on Boundless's website, they are greeted by a flashing message that says, "Aligning your book." Soon, a table of contents pops up on the screen.

In the case of *Principles of Economics*, Boundless offers a stripped-down text covering the same economic concepts. Mankiw is a snappy writer who starts off his chapter on taxes with an anecdote about Al Capone. Boundless's version reads more like a reference text, but its organization closely apes that of Mankiw's. Both books have 36 chapters and even share the same first sentence: "The word *economy* comes from the Greek word *oikonomos*, which means one who manages a household."

Boundless's replacement books are appealing to students like Heather Haygood, in her third year at Pikes Peak Community College in Colorado Springs, Colorado. She is using the Boundless version of *Biology*, which her school sells for $178.

$1,200

What the average U.S. college student spends on books and supplies annually

"I just refuse to spend that much on a book," Haygood said in an e-mail interview. "Lucky me i found it for free!!"

Aaron White, Boundless's cofounder and CTO, says the company uses a mix of human editors and technology to create its texts. It employs editors to locate public content from sources like Wikipedia, government websites, and Connextions, a repository of open-source academic material. That information goes into a content management system, which lets the company reuse explanations—say, of how DNA replicates—in multiple texts.

Commercial publishers are moving as fast as they can toward digital formats. Most now sell lower-cost electronic books through sites such as CourseMate, Kno, and Apple's iTunes. "We are in the heart of disruption now," says Bethlam Forsa, a vice president at Houghton Mifflin Harcourt, the largest K–12 textbook publisher in the United States.

Publishers of paper textbooks still enjoy some advantages. In K–12 education, states can't demand that poor students buy a computer or tablet, so they continue to distribute books. At the collegiate level, professors are reluctant to switch texts because they would have to revamp their courses.

Such barriers help explain why the open-source textbook movement, which has been around for a decade, has not gotten very far. "The marketing realities of distribution have a lot to do with why there hasn't been disruption," says Sanford Forte, founder of the 11-year-old California Open Source Textbook Project.

Diaz says Boundless's strategy is to use free books to amass a large audience to which it can later sell other "freemium" services, such as tutoring. He is vague about the paid products, which might not be introduced for another year or two. Even with such uncertainty, the company was able to raise $8 million in venture capital in February.

Mike Tyrrell, a partner at Venrock, which led the investment, says what caught his interest is that education in the U.S. still operates much as it did in the 1960s. With so much new technology being "applied against an industry that hasn't really changed," he says, "that makes for an interesting area to invest in."

Apparently, you don't need quaternions to do that math. —*Michael Fitzgerald*

Emerged Technologies

The Cleverest Business Model in Online Education

A startup called Duolingo taps the power of crowds to make learning a language free.

● Learning a new language is tedious and demands a lot of practice. Luis von Ahn doesn't want all that effort to be wasted. In fact, it might be a gold mine.

Von Ahn, a computer science professor at Carnegie Mellon University, is the co-creator of Duolingo, a free language-learning site that turns students into an online workforce. His software uses their answers to simple exercises in a translation service that he expects to charge money for.

It's clever stuff: an education that pays for itself. That achievement is important as education moves toward being given away online. Teachers and universities are now running into the same problem journalists and movie studios have faced: how

GOLDEN COSMOS

will they make any money if the content is free? No matter how cheap it is to pipe information across the Web, producing lessons and coursework is still demanding and expensive.

Duolingo, which launched in June, has raised $18.3 million in venture funding. It offers English lessons for Spanish and Portuguese speakers and lessons in Spanish, German, French, and Portuguese for English speakers. Around 300,000 people now use it each week.

The company is going up against popular language software such as Rosetta Stone (itself a less costly alternative to in-person lessons). But von Ahn thinks he has the edge, and not only because his classes are free.

"Most language-learning software providers have no incentive for you to learn," he says. "Once [they] get your $500, they're happy. We'll do a lot to get you to come back, because it really matters." His hoped-for translation business depends on it.

PROFESSIONAL HUMAN TRANSLATION (20 cents per word):
If Pakistan's history is any indicator, Musharraf's decision to impose martial law may prove to be the proverbial straw that breaks the camel's back.

That's why the company's 20 employees in Pittsburgh spend most of their time getting the software to teach better. Von Ahn says that so far about 30 percent of people who start learning a language will still be visiting the site a week later. That figure may sound low, but it's impressive for any Web service, he says. Duolingo users are drilled on new words using both written exercises and audio (the software can detect and assess their pronunciation). As they progress, their performance is used to decide what lessons they get next.

It adds up to a free course several hundred hours long that can take a student from zero knowledge of a second tongue to what von Ahn describes as "intermediate level" ability—the kind you'd need to get by on a foreign vacation or grasp the gist of a newspaper article.

The other side of the business comes in when students are asked to practice what they've learned by translating single sentences from one language to another. The sources for these sentences include English Wikipedia articles that don't have equivalents in Spanish.

GERMAN TEXT:
Falls Pakistans Geschichte ein Indikator ist, so könnte Musharrafs Entscheidung, das Kriegsrecht zu verhängen, jener sprichwörtliche Tropfen sein, der das Fass zum Überlaufen bringt.

Multiple students translate the same sentence; software compares those results to settle on a final translation. After many sentences are put through this process, they are combined to create a translation of an entire document. The results, says von Ahn, are better than an automated translation but typically just short of professional quality.

Duolingo's translation service is currently free, but before long the company intends to begin charging for "rush jobs" that have a deadline. Von Ahn says Duolingo will ask for less than the five to 20 cents a word that professional translators charge. The service is in pilot tests with a large media company, he says.

An inexpensive translation service could solve some big problems, particularly for newspapers in U.S. cities with large Hispanic populations. In August, for instance, the *Hartford Courant* launched a Spanish-language edition. But it was produced almost entirely using Google Translate. The results, which were spotty, drew negative reactions. (The newspaper later abandoned the idea.)

DUOLINGO:
If Pakistan's history is an indicator, Musharraf's decision to impose martial law could be the straw that breaks the camel's back.

This isn't the first time von Ahn has found a clever way to distribute small tasks among many people to solve a challenge, an approach he dubs human computation. He created something called the ESP Game, which turned labeling computer images into an online challenge. Google licensed that technology for its search engine and later also acquired ReCaptcha, a system Von Ahn created to help digitize blurry old books. Those distorted letters a website will sometimes ask you to copy to show you are human? That's ReCaptcha getting you to decipher text a computer can't.

Duolingo's design is inspiring others to look for new ways to apply human computation in education. "I think Duolingo is incredibly exciting," says Dan Weld, a professor of computer science at the University of Washington who helped organized a workshop last summer on how to use crowdsourcing in education. Weld thinks such methods could, for instance, turn students into a workforce that could correct or score the work of other students learning online. That could overcome a major shortcoming of massive open online courses, or MOOCs, which are encountering problems grading the work of tens of thousands of students.

GOOGLE TRANSLATE:
If Pakistan's history is any indicator, it could Musharraf's decision to impose martial law, be that proverbial straw that breaks the camel's back.

There's a "groundswell" in online education, says Weld. "But a lot of it is prepackaged video clips and other things we tried a long time ago that didn't go anywhere. We need more power and personalization." Achieving that solely with software is unlikely, he says, but properly directed crowds could provide the necessary intelligence.

Von Ahn has his own ideas along these lines. For example, he hopes to use the work of students who are learning computer languages online at places like Codecademy.

"You could imagine something with programming, maybe finding bugs in software as part of a course," he says. "We may try it." —*Tom Simonite*

SOURCE: DUOLINGO, GOOGLE TRANSLATE

Emerged Technologies

Online Exams: Big Brother Is Watching You

How can you tell if an online student has done the work? That's where webcam proctoring comes in.

● The boom in online education has created a job that didn't exist a few years ago: remote test proctor.

More than 100 people do this for ProctorU, a fast-growing startup founded in 2009. Sitting at computers in ProctorU's offices in Hoover, Alabama, or Livermore, California, the proctors use webcams and screen-sharing software to observe students anywhere as they take a test or complete an online assignment. As the students do the work on their computers, the proctors make sure they don't cheat.

It's a simple idea that could prove critical for the expansion of online education. Over the last year, several top universities, including Harvard, Stanford, and MIT, have begun offering free college courses to all comers. After attracting hundreds of thousands of students, these massive open online courses, or MOOCs, are now wrestling with how to determine which students are actually completing the coursework.

That will be vital because the chance to offer students "certified" results—and a course certificate—will probably be the key to ensuring that MOOCs are financially sustainable. EdX, the digital education partnership between MIT and Harvard, thinks it can charge students $100 or so if they want to obtain an official completion certificate. Other MOOC providers, such as the for-profit Udacity and Coursera, hope to make money by connecting their best students with employers.

With this in mind, edX, Coursera, and Udacity are working with the educational publisher Pearson to allow online students to take exams at testing centers run by Pearson. These centers can be found in more than 100 countries.

But even a network as widespread as that won't reach every prospective student. So more than 200 colleges and schools have hired ProctorU to oversee exams remotely. "Almost every class now has an online component to it," says Don Kassner, the company's CEO. "Schools are realizing the logistics of scheduling 350 students into a class for a final exam is difficult."

Many of the proctors hired by ProctorU are college students themselves. They're paid 75 cents per hour above minimum wage (which means $8.75 an hour in California) and get a raise of $1 per hour after a 90-day evaluation period. A proctor must watch and answer questions from as many as five or six test takers at one time, so Kassner says he tries to hire people who are proven multitaskers, like avid videogame players or people who have worked in restaurants.

GOLDEN COSMOS

Proctoring tests offers a remarkable window on the world, says Franklin Hayes, who has administered exams for the company since 2011. In addition to watching college students in their dorms and apartments, he's given tests to soldiers in Afghanistan and to people who hope to pass certification courses for highway paving. Once a police officer logged on to take a professional certification test from the laptop in his squad car.

Proctors must also steel themselves; some students can't resist exposing themselves to the person on the other end of the videoconference. "One of the things we train our proctors on is 'You're going to see some things you didn't want to,'" Kassner says.

7 in 1,000

Number of students caught cheating in online exams

Perhaps because the proctor-to-student ratio is higher than it might be in a traditional college classroom, cheating appears to be uncommon. The proctors file an "incident report" to a student's school if they spot something inappropriate; that might include a suspiciously severed Web connection or the student sneaking a peek at a textbook. Kassner says incident reports get filed for only seven out of every 1,000 exams.

Test takers see the proctor at the beginning of their exams but are free to minimize the videoconference window on their screens so they don't have to feel stared at. With the proctor invisible, it's not uncommon for students to forget and open a new tab in their Web browser to consult Google.

The proctors can see that happen through the screen-sharing software that test takers have to run on their computers. "We can intervene and say 'Please close that tab,'" Hayes says. "Most of the time, people are nice about it and close the tab." —*Brian Bergstein*

Researchers at Madrid-based Acciona Agua are investigating deep-sea desalination.

COURTESY OF ACCIONA

Spain: Improving Water Around the World

WATER—PURIFYING IT, TREATING IT, MANAGING IT— continues to grow in importance around the world, presenting new challenges and opportunities for companies in the water purification business. Even as water resources in many regions dwindle, cities and rural communities are searching for ways to increase the available supply of potable water and improve the quality and efficiency of water treatment. Wastewater is now seen as a resource, and this in turn creates the need for new methods of treatment.

These demands have led to a variety of technological solutions. They include improvements in desalination that have reduced energy consumption and the cost of treatment; advances in purification of drinking water; and new wastewater treatment systems that harvest energy from the organic waste material while supplying clean water to meet many rural and urban needs.

Spanish companies have become major international players in the water sector, in part by turning Spain's geographic and hydrological challenges into business opportunities. Many regions of the country, in particular its southern coast and the Canary Islands, boast abundant sun but little rainfall; so Spanish companies have acquired vast experience in both desalination and water treatment and purification. Today, Spanish water treatment companies are operating in more than 30 countries, in North and South America, Australia, North Africa and sub-Saharan Africa, the Middle East, and India and China.

Desalting the Sea

Spain's leadership role in the field of desalination stretches back to the 1960s, when the country needed to increase potable water supplies on the sunny, tourist-attracting Canary Islands. Companies gained experience in desalination on those islands and then moved onto the Spanish mainland, purifying water for the hot, dry south, and supporting the growing agricultural sector that supplies food to much of Europe. Today, desalination enhances the water supplies beyond Spain's arid regions; in 2009 the city of Barcelona built the Prat de Llobregat desalination plant, which can supply up to 20 percent of the city's drinking water. And Spain desalinates more water than any other country in Europe, placing it among the world's top producers.

Spanish companies have capitalized on this success: Angel Cajigas, director of ATTA, Spain's water-treatment business association, says that of the world's 20 companies most active in desalination, seven are Spanish.

As a result, Spanish companies take part in building and operating some of the largest desalination plants in the world. Acciona Agua, based in Madrid, is part of a consortium to build a major plant in Adelaide, Australia, while in 2011 Madrid-based Valoriza Agua opened a plant in Perth that can treat 300 thousand cubic meters per day. Madrid-headquartered Abengoa Water was the first foreign company to secure contracts to build and operate desalination plants in China, following its success in India and in Algeria. While Israel is known for its own desalination technologies, Valoriza Agua is now partnering with Israeli companies to build one of the world's largest desalination plants, incorporating ultrafiltration pretreatment—a plant which is expected to supply a full 15% of Israel's water needs by the end of 2013. Grupo Seta is working in a number of countries, including the Philippines, Tunisia, and Morocco.

Even in the United States, water-poor regions have turned to desalination as a supply solution. Acciona Agua took over the Tampa Bay desalination plant, which had been beset with problems since its construction began in 1999. Today, that plant purifies 25 million gallons a day and supplies 10 percent of the region's drinking water. Another company working in the U.S., Abengoa Water, has many projects in process in Texas, according to president Carlos Cosín. He highlights the company's planned expansion into Oklahoma, Arizona, and California, all of which were hit by drought in 2012.

Cosín points out that the decreasing costs of desalination now make it competitive even in developing countries; Abengoa Water began construction on a new plant in Accra, Ghana in 2012. The governments of Ghana and China are also working with Abengoa to develop desalination plants to supply industrial projects, a new oil field in Ghana, and an island industrial complex in China: "How can they bring industry to the area, and attract overseas investors, if they have no water resources?" Cosín asks.

One aid to Spanish innovation is that, in addition to its large, attention-grabbing desalination plants, Spain's coastline is also dotted with hundreds of smaller plants. These not only provide experience in many real-world situations, but they offer companies ideal laboratories to test new technologies or treatments.

Bilbao- and Madrid-based Cadagua has used its Spanish plants, including one in the Spanish territory along Africa's northern coast, to acquire experience in and feedback about features such as new types of pretreatment (to remove solids that could harm the reverse-osmosis (RO) membranes used for filtration). Cadagua's CEO Antonio Casado describes his two-year partnership with MIT—it began in 2012—to take advantage of MIT's modeling and simulation expertise. That computer-based modeling work, leveraging Cadagua's water-treatment knowledge, will help optimize desalination's energy use.

Acciona Agua's researchers are investigating deep-sea desalination, moving from shallow near-shore water retrieval into deeper offshore waters. This move has the potential for greater energy efficiency, says Jorge Malfeito, director of research and development, and could eventually take advantage of the company's offshore wind turbines (currently in development) to provide electricity for the system.

But desalination is not just for seawater. The technology can also be used to improve the quality of a brackish aquifer or a river polluted with high levels of sulfates or nitrates. The Llobregat river that flows through Barcelona was polluted with organic matter, which can quickly foul the membranes of an RO desalination plant. Instead, Valoriza built the world's largest electrodialysis reversal system (EDR); in such a system, an electric current moves the salt ions to the electrodes, and a membrane separates the fresh water from the salts.

Domingo Zarzo, head of Valoriza's research and development department, says the company has vast experience providing desalinated water for agriculture in southern Spain. "Desalination can be tailored," he explains, allowing the company to provide the exact quality of water that a crop demands. Valoriza is now exporting this technology and its business model to meet agricultural needs in the Middle East, South America, and Australia.

At Acciona Agua's research facilities in Barcelona, company engineers test technologies, such as advances in membranes and a variety of new desalination techniques, for instance a pretreatment that employs floating plastic balls. These balls create an optimal surface for bacteria to grow and degrade organic matter, helping clean material from water before it can foul sensitive membranes. Together, these research lines enable new plants that can treat water in smaller facilities, providing savings in construction and in operation costs. Acciona Agua has also developed a technique to target red tide; the seawater is bubbled with air, and this allows the algae to float to the surface where they can be more easily removed. Malfeito says the company is already introducing advances like these into their projects under construction abroad, such as a new desalination plant for a mining operation in the Chilean desert.

Ever Purer Water

In addition to desalinating sea water, Spanish companies provide potable water—from rivers or aquifers—to millions of customers around the world. Cadagua, which has worked in China, Morocco, Saudi Arabia, and other coun-

Bilbao- and Madrid-based Cadagua has partnered with MIT modeling and simulation experts to optimize energy use.

COURTESY OF CADAGUA

Egypt's New Cairo Wastewater Treatment Plant, a joint venture of Orascom Construction Industries and Madrid-based Aqualia, will serve more than one million people.

COURTESY OF AQUALIA

tries, won a contract for a conventional fresh-water potable treatment plant now under construction in southern India. Acciona Agua supplies potable water to more than 12 million customers via more than 100 drinking-water plants. Abengoa's drinking-water plants are located in more than 20 countries, among them Peru, Mexico, Sri Lanka, and Morocco.

And with growing need for clean water, the industry also has new challenges to meet. To keep costs down, all companies are moving to reduce the energy needs of these facilities and diminish their overall footprints.

In the realm of physical footprints, Madrid-based Grupo Seta, in addition to considering the characteristics of the large-scale desalination and water-purification facilities the company has worked on, also focuses on small-scale plants. Their mobile modular purification systems can quickly supply drinking water in isolated regions or following catastrophic events, and they have provided clean water to the Spanish army in Afghanistan and Iraq. Similar systems have been certified and used by the International Red Cross, as well as by various public and private institutions.

Water resource managers and governments around the world are now aware of the increasing quantities of pollutants that end up in wastewater, which can include pesticides, drugs (even ones as commonplace as ibuprofen and acetaminophen), and hormones, such as those used for birth control. These drugs are not entirely removed by wastewater treatment, and can end up in river systems that then provide the source of drinking water further downstream.

Some of these substances are removed by conventional treatment, says Gloria Garralón, Cadagua's director of research and development, but others are more complex to degrade during either wastewater treatment or potable-water purification. "The technologies exist to create ultrapure water, but at what price? If it demands such a high input of energy that it causes harm to the atmosphere, then it doesn't make sense."

But there is increasing recognition that removing such pollutants from our water will demand the optimization of existing technologies or the development of new ones. "Up until now, providing drinking water has been very easy," says Abengoa's Cosín. "You'd remove suspended solids, chlorinate the water, and then provide the water for any municipality. Now it's not so simple."

Water that has been contaminated with pesticides or pharmaceuticals demands a higher level of treatment, and Cosín says he's convinced that membranes—though expensive now—will eventually provide an important method of treatment. The company is involved in early-stage pilot projects to test such systems.

In order to better treat water and remove these sorts of so-called emerging contaminants, Acciona Agua is investigating a number of advanced technologies. Instead of chlorine, the company is studying the use of advanced photochemical oxidation technologies that include treating water with ozone, ultraviolet radiation, and peroxide, all to purify water and degrade pesticides and pharmaceuticals. They're also researching new nanoscale materials that can serve to catalyze such photochemical disinfections. At the moment, this technology is still too energy-intensive for commercial use, so company engineers are studying methods to reduce its energy consumption.

Waste into Resource

Though many people prefer to ignore it, wastewater treatment is a crucial part of the water cycle, and one, say experts, which provides many opportunities for improvement. In particular, with so many urban and rural areas in need of water, water managers see great potential in purifying waste and providing clean water.

In a traditional sewage treatment plant, gravity is used to separate the solids, called sludge, from the liquid. That liquid is then cleaned further using a variety of methods, such as using bacteria that breaks down organic matter, while the sludge is dewatered (partially dried). Sometimes the remaining sludge is sent to a landfill, and sometimes it is given to farmers to apply on their lands. That system is not optimal, however, because it

does not break down a good many pollutants and metals that are often undesirable for agricultural applications.

"This basic wastewater technology—sludge—was first described in 1914 in Manchester [England]," points out Frank Rogalla, Aqualia's director of innovation. (Madrid-based Aqualia is involved in water purification, desalination, and wastewater treatment in more than 17 countries on four continents.) "So why are we still using it 100 years later?" In addition, he explains, what works for rainy, chilly England is not necessarily ideal for countries like Spain and elsewhere around the world, where heat and infrequent rains can lead to warmer and more concentrated waste.

That warm concentrate may be better suited to treatment with different technologies, such as those that employ microorganisms to convert the waste to energy. When the organic matter is consumed by bacteria that produce biogas (mostly methane), the biogas can be used as a form of natural gas for electricity production. This process also breaks down some of the contaminants in sludge.

Warm, nutrient-rich water is the perfect feedstock for another resource: algae, which can be used for biofuel. Aqualia launched a project, funded by the European Union, to construct the first wastewater-fed algal ponds in southern Spain. This five-year project was initiated in the spring of 2012 and aims to create a 10-hectare demonstration site.

New technologies are replacing the gravity filtration treatment method. In a membrane bioreactor (MBR) system, the plant separates out the liquid via a filtering membrane. The water can be considered either ultrafiltered or even microfiltered, depending on the size of the pores in the membrane, and the process results in a very high quality water that can be directly reused for applications like city parks and golf courses. The remaining sludge is then digested and broken down by microorganisms.

MBR systems have not been particularly popular until recently because of

A water treatment facility in Lleida province in northeastern Spain

their relatively high cost, but advances in membranes that can operate in such a challenging environment have helped reduce the price of the systems. Meanwhile, many cities are demanding more of increasingly precious water, and the highly purified water from MBR plants can help meet those needs. Cadagua was the first company to build a large MBR facility in Spain, and is now building such a system in Oman, where the water will be treated to a high enough level for reuse for nonpotable needs. "There are two advantages of the system," says Javier Arrieta, Cadagua's director of engineering. "One is that we produce ultrafiltered water, which can be directly reused for irrigation." Also, he adds, because the solids become highly concentrated, the same volume of waste can be treated in a facility one half or even one third the size of a conventional plant.

"Probably the new trend in water is reuse—and it's becoming the new global market in water. Total reused water [now] is less than 4 percent, and if we want to be ambitious about increasing new resources in water, all that water has to be reused," says Cosín of Abengoa.

In the future, wastewater will increasingly be viewed as a resource, providing both water and energy (from its organic matter). Wastewater also contains significant levels of both phosphorus and nitrogen, both of them in heavy demand in the agricultural and industrial markets. Methods to recover those nutrients separately from the waste could create a more efficient, closed-loop system. Today, for instance, nitrogen for fertilizer production is removed from the atmosphere in an energy-intensive process to make ammonia. But urine wastewater yields 90 percent nitrogen. One challenge in accessing the nitrogen and phosphorus, says Rogalla, is that in conventional flush toilets they are diluted with massive amounts of water. In hot, water-poor countries, Rogalla says it makes better sense to avoid wasting water and recover these nutrients at the source. Aqualia is investigating techniques to recover nitrogen and phosphorus via alternative infrastructure approaches. This would be particularly appropriate for countries that are still building their infrastructure, many of which see clean water as a valuable resource.

Aqualia has also set up a pilot plant for a potato chip manufacturer in southern Spain to test new methods for using anaerobic pretreatment—without oxygen—to convert waste to biogas. And, working within the current waste system, Aqualia is developing improved systems to disinfect sludge and destroy contaminants. Acciona Agua is also studying methods to optimize anaerobic digestion, which will improve the production of biogas and reduce the energy consumption of wastewater facilities.

Abengoa Water is developing a process, in coordination with an engineer at MIT, in which they will use the energy from organic matter to create high temperatures and pressures that remove all water from the sludge and create an inert waste that resembles sand. Abengoa has just opened a pilot plant in Seville to test the technique.

All these areas—desalination, water purification, and wastewater treatment—are critical around the world. In all of them, Spanish companies continue to provide high-quality solutions and innovative new approaches to solving current and future water challenges.

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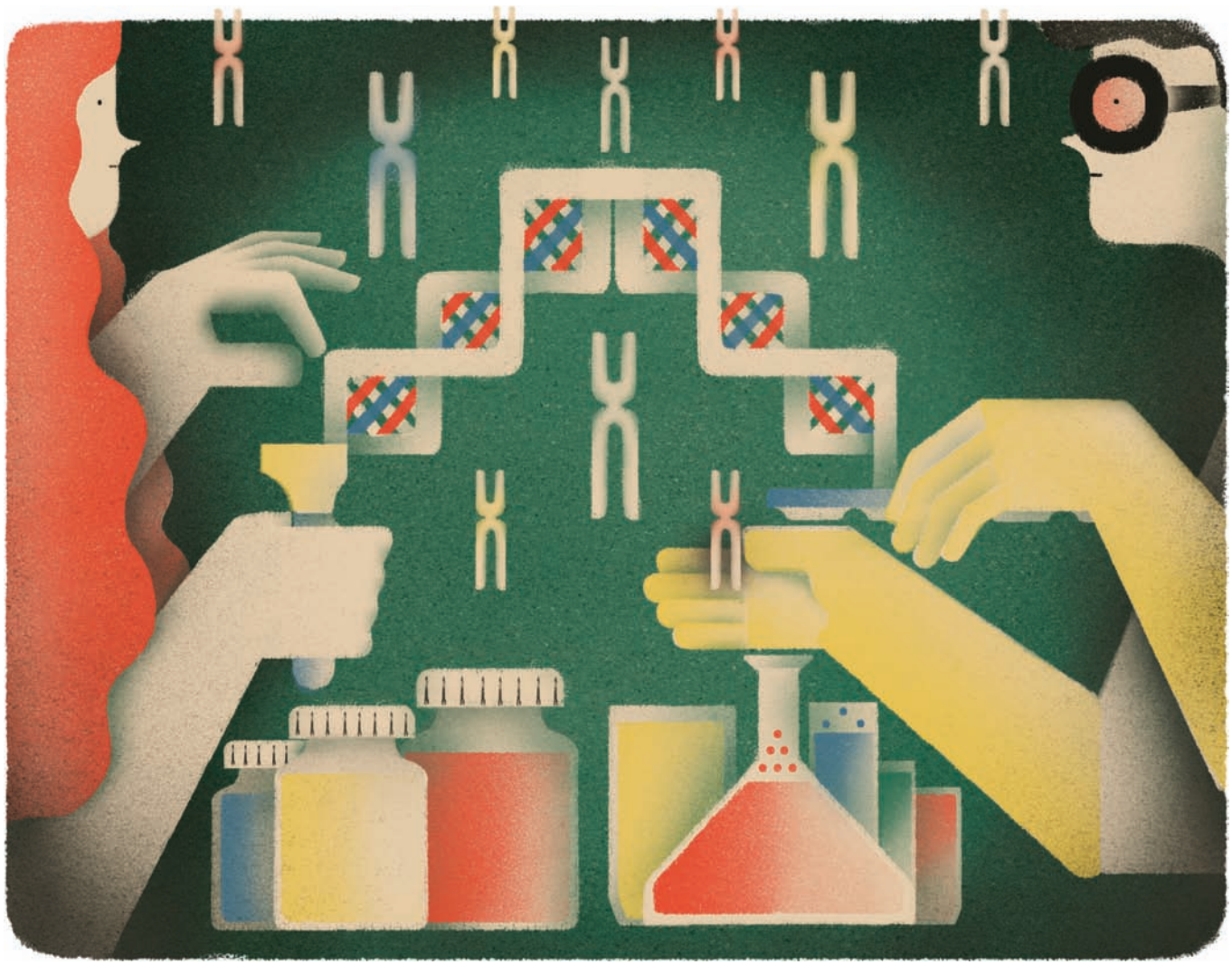

SERGIO MEMBRILLAS

Why We Have a Right to Consumer Genetics

It's hard to get straightforward health guidance from personal genome tests, which are banned in some places. But one way to make them more meaningful is to let more people buy them.

By Susan Young

It was easy to send my spit to 23andMe, a personal genetics company based in Mountain View, California. I filled the tube that came by mail with a few milliliters of saliva, mixed in the preservative solution, and screwed on the cap, and my sample was ready to be mailed. Soon I would know my risks for Alzheimer's, breast cancer, and obesity, and I'd have an idea what medications I should avoid.

Well, not exactly. As in most of human genetics, what's tricky about consumer-friendly tests is interpreting the significance of DNA variation. A couple of weeks after shipping off my tube, I

23andMe Personal Genome Service

got an e-mail notice that my results were on 23andMe's website. While it was fun to click through my ancestry reports, I was less compelled by the analysis of the genetic traits that could influence my health.

The biggest disease risk in my report? I have a 5.2 percent chance of developing restless leg syndrome later in life—24 percent greater than the average person, who has a 4.2 percent risk. My risk for Alzheimer's is slightly lower than average and my risk for obesity is typical. But these conclusions are not particularly meaningful. New studies could uncover variants in my genome that carry a significant risk for dementia later in life. And for obesity, genetics can be overshadowed by lifestyle.

The results did contain some useful information, however. For example, my genome carries signs that I have an above-average sensitivity to a common blood thinner. Currently, I don't need such a drug, but if that changes—say, if I suffer a heart attack—then this knowledge could be critical in helping a physician determine the proper dose of a potentially life-saving medication. I also found motivation to switch to decaffeinated coffee—my report says I am a slow caffeine metabolizer, which is associated with a risk of heart attacks for multi-cup-a-day users like me.

Because interpreting the results is uncertain and the relationship to disease risk is sometimes weak, critics oppose selling these tests directly to consumers.

In some ways, I was lucky that I found nothing monumental in my report. "About 40 to 50 percent of customers end up with results like yours—they don't have anything that jumps out very strongly," says Joanna Mountain, senior director of research at 23andMe. But for many, the results are potentially more significant. "For example, for macular degeneration, the risks [that are indicated in the reports] range from 0.1 percent up to 74 percent," Mountain says. "For heart disease, there's a big range—10 to 50 percent."

It can be difficult for most people to understand what these ranges mean, though. And for now, it's not clear how receptive the medical community is to helping. "I've had patients bring me these reports, and I don't spend a lot of time reviewing the results because this is not a test I would have ordered," says Sharon Plon, a geneticist and physician-scientist at Baylor College of Medicine in Houston. What's missing is proof that these tests can inform and improve patient care, she says: "Physicians are going to shy away from using them unless they become part of evidence-based medicine."

Typically, personal genetics companies like 23andMe determine which particular DNA base pairs each customer has at places in the human genome that are known to vary from person to person. The companies then interpret the results of scientific studies to tell customers what their results mean. The tests are sold directly to consumers for as little as a few hundred dollars, without the involvement of a health-care provider. In 2010, the FDA sent letters to several companies warning them that their products were considered medical devices subject to regulation, although exactly how the oversight would happen still hasn't been firmly established. That same year, the Government Accountability Office sent samples to four companies and got conflicting results.

Because interpreting the results is so uncertain and the relationship between genetics and disease risk is sometimes weak in the first place, some critics oppose selling these tests directly to consumers. Such sales are restricted in some countries, such as France, and in a few U.S. states, including New York and Maryland. The American College of Medical Genetics and Genomics' stance is that the tests should be taken with guidance from an expert who can assess the validity of the results and explain the actions that could be taken in response, says executive director Michael Watson. New studies on the connection between DNA and disease or drug response are published every week. Some of these studies establish a previously unknown link; others may add more weight to a known association; yet others may contradict or disprove what was once thought to be meaningful. "The results of many of these tests are very complex," says Plon.

Yet this "father knows best" attitude is irksome to many; surely people have a right to such data about themselves, regardless of the complexity and ambiguity of the results. "To tell somebody you don't have the right to access information about your own biology, for any reason, is pure paternalism," says Misha Angrist, an assistant professor at the Duke University Institute for Genome Sciences & Policy. Moreover, most family doctors, and even many specialists, are unfamiliar with genetic tests, and those who've been out of medical school for several years may have no training in genomics at all. In many cases, the consumer might well be better informed.

"I don't think we give enough respect to consumers," says Eric Topol, who is director of the Scripps Translational Science Institute. Topol is troubled by efforts to prevent the tests from being sold to consumers, arguing that patients could be the best advocates for bringing genomics into medicine. "We should be in an era of democratizing DNA," he says. "I think

that if we block the consumer from direct access, that's really unfortunate, because they are ultimately going to drive this story. If we keep it open to consumers ... eventually, that will force the doctors to get up to speed."

In 2011, the *New England Journal of Medicine* published a survey that Topol and colleagues conducted with more than 2,000 customers of the genetics company Navigenics. It asked them how well they understood the information that Navigenics gave them and whether they exhibited signs of psychological trauma in response to being told potentially ominous things about what their medical future might hold. "Turns out people assimilate this information very well, and there is no evidence of psychological disturbance," Topol says. "People really grasp this information."

For now, the biggest problem with consumer-friendly genetic products is simply that they may be medically inconclusive for most people. Indeed, I was more interested in the result that my genome was 2.7 percent Neanderthal (a tad higher than the 2.6 percent average for people of northern European descent). But as the costs of medical care continue to skyrocket and many individuals look for more opportunities to control their own health, these tests—if they become more powerful—could become an essential tool for understanding our bodies and helping guide us to behaviors and choices that will lead to better outcomes.

What will keep me returning to this technology will be the updates sure to come from the scientific community as researchers continue to decipher the medical meaning of the human genome. Of the million DNA variants that 23andMe examines, fewer than 1,000 are part of the health report. The rest wait for evidence linking them to traits. In some ways the story of consumer genetics parallels that of human genomics as a whole: the challenge ahead is to figure out what specific genetic variations signify and then study them in a health context to see whether they make a real difference to patients and doctors. It would be a shame to restrict personal genetic tests now, before they have a chance to become more useful. Rather, consumers should be allowed to explore their genetic makeup to help figure out how the information can be used to make smarter medical decisions.

Susan Young is MIT Technology Review*'s biomedicine editor.*

This Shapeways 3-D printer is working from a digital design to create an object out of nylon.

The Difference Between Makers and Manufacturers

Fans of 3-D printers and digital design tools argue that these technologies will transform the way we make goods. But can the "maker" movement really produce more than iPhone covers and jewelry?

By David Rotman

It's not surprising that 3-D printing has captured the imagination of so many technologists. Create a digital design file or download one from numerous sites now on the Web, adjust a few settings, hit "Make," and a machine will slowly print the thing, precisely depositing ultrathin layers of a material (usually a cheap plastic) until the object of your design sits before you. It's a function instantly recognizable to any reader of science fiction.

The basic technology has existed for decades: a group of engineers at MIT patented "three-dimensional printing techniques" in the early 1990s. Companies such as General Electric have used additive manufacturing, as industrial versions of the technology are often called, to make prototypes and complex parts for airplane turbines and medical instruments. But the real cause of excitement is the emergence of 3-D printers that are affordable for consumers—at least those with a thousand dollars or more to spend.

Makers: The New Industrial Revolution
Chris Anderson
Crown Business, 2012

Producing Prosperity: Why America Needs a Manufacturing Renaissance
Gary P. Pisano and Willy C. Shih
Harvard Business Review Press, 2012

The seemingly magical ability to "turn bits into atoms," as advocates like to say, has made 3-D printers iconic tools for a growing number of people intent on do-it-yourself manufacturing. Depending on whom you choose to believe, they are comparable to the first affordable personal computers in the early 1980s—or to the Internet itself.

In *Makers: The New Industrial Revolution*, Chris Anderson describes the swelling community of people determined to create their own stuff using 3-D printers, laser cutters, advanced design tools, and open-source hardware. Anderson, who until a few months ago was the editor in chief of *Wired* magazine, describes the "maker movement" with unabashed enthusiasm, pointing to the proliferation of "makerspaces" in which people can use shared facilities and equipment to fabricate their designs and describing popular gatherings called Maker Faires, including an annual event attended by some 100,000 people in the Silicon Valley city of San Mateo, California. In Queens, directly across the East River from midtown Manhattan, a company called Shapeways has created what it calls the "Factory of the Future," equipped with some 30 industrial-size 3-D printers to produce the various designs of its digital customers.

Though many of the products created this way so far are one-off novelty items and customized tchotchkes, Anderson insists that the movement is about more than high-tech crafts for hobbyists. In particular, he delights in its Web-like culture of sharing designs and collaborating in online communities. The ability of individuals and small startups to design

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items and either print them or send off the digital files and have them made is already transforming manufacturing, he proclaims, replacing mass production with custom production: "The idea of a 'factory' is, in a word, changing."

What kind of future might the maker movement bring us? Anderson envisions it could mean that "Western countries like the United States regain their lost manufacturing might, but rather than with a few big industrial giants, they spawn thousands of smaller firms picking off niche markets."

The problem with this thesis is that Anderson makes little effort to explain how a community of creative and enthusiastic individuals or small startups might give rise to an industrial movement capable of transforming and revitalizing manufacturing. His analyses often seem incomplete: "Because of the expertise, equipment, and costs of producing things on a large scale, manufacturing has been mostly the provenance of big companies and trained professionals. That's about to change. Why? Because making things has gone digital: physical objects now begin as designs on screens, and those designs can be shared online as files." The reader is left wondering: how does sharing digital designs change the fact that most of the goods we want and depend upon, from iPhones to jet planes, still require the skills and budgets of large manufacturers? Equally frustrating, Anderson often relies on shaky historical comparisons, suggesting that makers are today's version of garage tinkerers like Silicon Valley's Homebrew Computer Club, which spawned the Apple II in the 1970s. For the maker movement, merely sharing the principles and spirit of those renowned innovators hardly guarantees comparable success.

Anderson's prediction that many consumers will move away from cheap mass-produced goods to the work of "industrial artisans" could someday come true. But, again, his evidence is unconvincing: "Just think of couture fashion or fine wines," he writes. These are small markets. And for many other goods, people often prefer mass-produced versions, because they cost less and are at least standardized, if not always great, in quality. Anderson suggests that "what the new manufacturing model enables is a *mass market for niche products*." But he doesn't attempt to quantify the economic impact of this shift to artisanal goods. He points to what he calls "happiness economics" rather than conventional macroeconomics as the real justification for custom production: "What's interesting is that such hyperspecialization is not necessarily a profit-maximizing strategy. Instead, it is better seen as meaning-maximizing."

This sculptural clock was designed using CAD modeling and printed using nylon powder.

COURTESY OF GILBERT 13

Perhaps most damning for his ambitious claims about the impact of the maker movement, Anderson has little interest in how most things are actually manufactured. He locates the real value of the subculture in the creation and sharing of digital designs for stuff. Anderson is agnostic about what should happen next: send the design to your 3-D printer

or upload it to the cloud and send it to a contract manufacturer in China, he suggests. While 3-D printers will no doubt get more versatile—some advanced models are already able to handle an impressive range of materials, including certain metals—additive manufacturing will remain, at least for a while, better suited to making parts than to building entire machines or devices. As a result, Anderson's vision for his industrial revolution is too often limited to stuff that can be fabricated by a 3-D printer and laser cutter or easily assembled by a manufacturer acting as a cloud service.

This is frustrating, because the way we make things in the United States is in desperate need of revitalization. The country is still a manufacturing powerhouse, but according to some estimates, it now trails China as the world's leading producer of goods (see "Can We Build Tomorrow's Breakthroughs?" January/February 2012). Perhaps more troubling, it is also behind many Asian and European countries in advanced manufacturing.

In *Producing Prosperity: Why America Needs a Manufacturing Renaissance*, Gary P. Pisano and Willy C. Shih, professors at Harvard Business School, list critical technologies in which the United States has lost or is at risk of losing its manufacturing prowess. Among them are rechargeable batteries, liquid crystal displays, and semiconductors (70 percent of the world's foundry capacity is in Taiwan). It is no longer feasible to make e-ink readers in this country, though the technology was invented here.

Shih rejects the notion that innovative products can reliably emerge when designs are shipped off for others to produce. Rather, he suggests, truly advanced products more typically come about when designers and inventors understand manufacturing processes. "You can create a CAD design," he says, "but you need to understand what a production process can and can't do."

Many types of manufacturing require a sophisticated series of steps and processes to be done in precise sequence. Selecting the right materials and technologies is key to high-quality, low-cost results. If designers don't understand the manufacturing processes and materials that are practical, they will never come up with the most advanced and compelling new products. It's a lesson that has been repeatedly learned over the last decade in the development of new clean-energy technologies. Innovators may create smart designs for technologies such as solar panels, but ignoring the costs and practical details of manufacturing the new products is a sure path to failure.

It may be too much to expect that Anderson's makers will have much impact on the manufacture of high-tech goods. But scattered within the maker movement are many clever ideas about sharing, collaborating, and creating consumer-friendly designs that could help revitalize our thinking about how to produce things. (Consider, as a precedent, Anderson's example of how open-source software, once dominated by communities of individual programmers, has been adopted by large companies.) One also suspects that the manufacturing sector could benefit from the entrepreneurial spirit and creative instincts of the makers Anderson profiles, as well as from the imaginative uses they've found for 3-D printing.

But to get anywhere near Anderson's lofty goal of revolutionizing industry, individual makers and small startups will have to collaborate not only with each other but also with large industrial firms. And to do that, the maker movement will need to be more curious and knowledgeable about how stuff is actually made.

David Rotman is the editor of MIT Technology Review.

The Spectrum Crunch That Wasn't

Tiny transmitters, spectrum sharing, and new information-coding technologies promise to keep wireless data capacity increasing for years.

By David Talbot

Take a look around at the next ball game or concert you attend. You'll see thousands of fans snapping photos and videos and e-mailing them to friends. Those armies of smartphone owners—and their tablet-toting brethren—are contributing to a striking increase in wireless data usage: Cisco Systems estimates that mobile data traffic will grow by a factor of 18 by 2016, and Bell Labs predicts it will increase by a factor of 25. Intuitively, there's a problem: all these photos and videos go over the airwaves. Yet just a few sections, or bands, in the spectrum of radio frequencies are available to the wireless carriers, which paid billions of dollars for them. Vastly more frequencies are reserved for other uses, from television and radio to aviation and military applications. Data traffic is growing so rapidly that carriers have imposed usage caps and raised prices. Surely, these two basic realities—exploding data use on the one hand, limited bands of spectrum on the other—must mean we will soon run out of airwaves for our gadgets, right?

Report to the President: Realizing the Full Potential of Government-Held Spectrum to Spur Economic Growth
President's Council of Advisors on Science and Technology
July 2012

Just two years ago the chairman of the U.S. Federal Communications Commission, Julius Genachowski, suggested as much. He said the U.S. wireless industry desperately needed to get its hands on underused parts of the spectrum controlled by government agencies or TV broadcasters. Otherwise, wireless companies would find that demand for their services would outstrip their ability to provide them. "If we do nothing in the face of the looming spectrum crunch, many consumers will face higher prices as the market is forced to respond to supply and demand," he declared. Similarly, an AT&T executive, Jim Cicconi, said that "the need for more spectrum is an industry-wide issue and problem."

But these claims were premature. For one thing, spectrum "crunches"—mobile phone usage that overwhelms the available wireless frequencies—would occur at highly specific locations and times. Sometimes, alternative strategies can completely solve these localized problems.

Look around that stadium, for instance, and you'll probably find milk-carton-size boxes tucked away in the rafters. These are short-range Wi-Fi receivers, operating on unlicensed portions of the radio spectrum. Your phone can send data through them instead of on the long-range cell-phone frequencies. The Wi-Fi boxes mop up all the data you send, and route it out of the stadium over a wired Internet connection. So the data sent by you and nearly everyone else in the stadium doesn't touch the precious spectrum that the wireless carriers claim

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is running out. That clever trick is just one example of the new strategies and technologies that can be brought to bear.

The entire spectrum system is managed inefficiently. A recent advisory report to the White House made that clear enough, and it emphasized that sharing wireless frequencies more widely—rather than parceling each band out to a limited set of users—could increase wireless capacity by a factor of thousands. For example, many sections of the airwaves that are reserved for TV stations and federal agencies go unused. That's partly because some regions have only three local TV channels and no one needs the remaining spectrum set aside for TV broadcasts. Or a military weapon system that gobbles spectrum in San Diego uses little or none in New York. "We don't have a spectrum crunch so much as we have a spectrum policy crunch," says David Tennenhouse, Microsoft's vice president of technology policy and a former MIT professor and Intel executive. "The so-called 'spectrum crunch' really reflects artificial spectrum scarcity."

To document this artificial scarcity more precisely, his company has launched a project, called the Microsoft Spectrum Observatory, to measure where and when bands of radio frequencies are actually being used, starting in Washington, D.C., Seattle, and Redmond, Washington. Tennenhouse hopes it is the first step in a far broader data-gathering effort that leads to smarter spectrum regulations. Pointing to the runaway success of Wi-Fi, which covers only short ranges and works on open, unlicensed frequencies, he adds, "The challenge now is to extend those proven successes to enable wider-area broadband access using other underutilized portions of the spectrum."

Some early efforts at frequency sharing have begun. For example, some television channels that go unused in a given geographic area, referred to as "white spaces," can now be used by other devices. And in December, the FCC recommended that researchers and companies be allowed access to frequencies that have been reserved for radar systems.

Many more airwaves could eventually be shared with the help of cognitive radios, which sense available frequencies and shift between them in milliseconds to avoid interference with other devices. Some of the first outdoor tests are under way at the University of Colorado. Groups elsewhere, including Virginia Tech, the University of California, Berkeley, and Rutgers, are also working on the technology. However, at least for now, rigid regulations don't allow widespread use of flexible technologies like cognitive radio.

It's not that the entire subject of a spectrum crunch is a red herring. Radio frequencies are a limited resource, and some bands aren't well suited to long-distance communications. Wireless carriers can't endlessly install new base stations, those towers atop office buildings or hillsides (sometimes disguised as trees), because eventually the signals would interfere with those from other stations. But shorter-range transmitters and receivers that use dedicated cellular frequencies—called small cells—can already fill gaps in coverage. The smallest of these, called femtocells, can be as cheap as $200 and give clear service in homes and offices while keeping the load off large base stations, much like those Wi-Fi gadgets in the stadium rafters. "Small cells are the hottest thing in the wireless industry right now," says Jeff Reed, director of the wireless research lab at Virginia Tech.

John Donovan, an AT&T executive vice president, said this fall that while the company had bought additional spectrum rights and wanted still more, the immediate crisis had passed, and that half the new demand through 2015 would be handled by small cells. Such technologies have emerged far more strongly than anticipated. "If you looked a few years ago, you'd say we'd be out of spectrum by now," says Vanu Bose, founder of Vanu, a wireless-communications company in Cambridge, Massachusetts. Bose, along with Reed, was a technical advisor on the White House report. "There are lots of ways to satisfy the demand," he says. "Adding spectrum [for commercial services] is certainly one of them, and so are small cells, alternative offloading technologies, and innovations we haven't even conceived of yet."

Eventually, new technologies might free up airwaves by making wireless data transfers happen much more quickly. For example, MIT researchers have shown it's possible to reduce the amount of back-and-forth communication required to deal with dropped packets of data. While the technique may be a few years from being widely implemented, lab demonstrations show that it could increase capacity tenfold. That means you could download your video 10 times faster than you do now, freeing the network that much sooner for someone else to use.

AT&T acknowledges that a predicted spectrum crisis has passed. Says a wireless expert: "There are lots of ways to satisfy the demand."

So can new technology stave off a spectrum shortage forever? Perhaps not, but Microsoft's Tennenhouse says that decades of research advances are waiting to be applied to the problem: "Right now, we have a 15- to 20-year backlog of new technologies and architectures ... which can take us a long way into the future."

David Talbot is chief correspondent for MIT Technology Review.

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Demo

01

Beyond the Touch Screen

A microfluidic panel lets users push buttons on a flat interface.

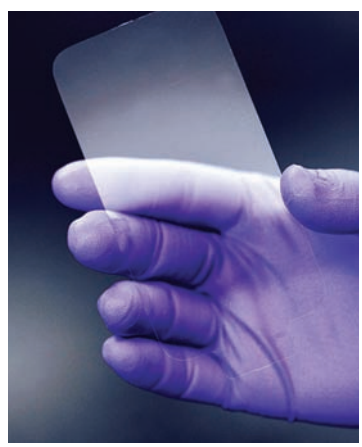
By Jessica Leber
Photographs by Timothy Archibald

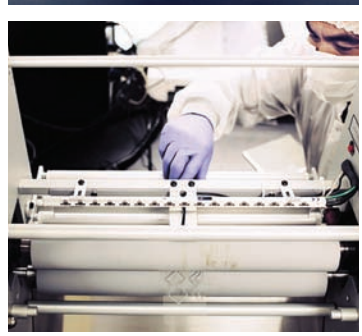
Tactus Technology, a startup in Fremont, California, is prototyping touch-screen hardware with buttons that emerge when you need the feel of a physical keyboard and disappear when you don't. The approach, in which a fluid-filled plastic panel and cylindrical fluid reservoir replace the usual top layer of glass, is among a crop of emerging technologies aimed at adding tactile feedback to make screens feel like old-fashioned keyboards.

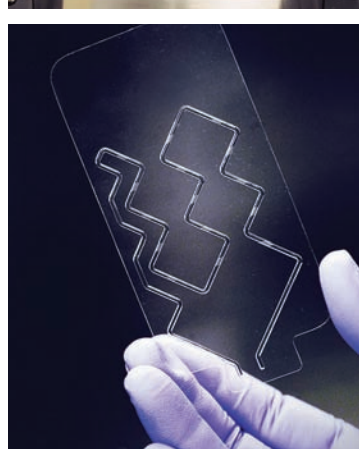
Touch screens are ubiquitous: in 2012, 1.2 billion were made for smartphones and 130 million for tablets, and they're showing up in everything from game consoles to car navigation interfaces. But typing on them can be difficult. Tactus is trying to solve that problem. The company's cofounder and chief technology officer, Micah Yairi, helped create a multi-layered panel that contains microchannels filled with a proprietary oil. When signaled by,

01 Craig Ciesla

02 A clear polymer base (top) is fused in a laminator (middle) with a similar sheet that has microfluidic channels and an elastomeric cover layer. The resulting panel (bottom) is one millimeter thick.







02

03

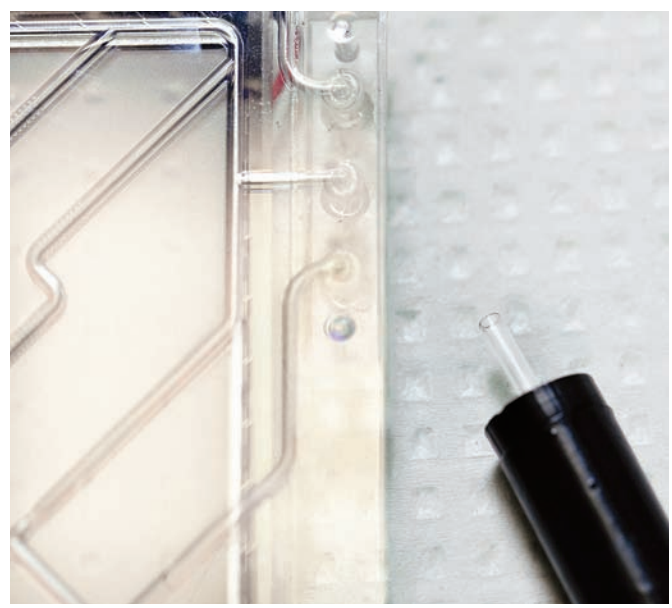
03 The finished panel contains millimeter-wide channels studded with clusters of 250-micrometer holes through which fluid is discharged to fill buttons when the panel is activated.

04 Tubes are used to fill the panel with a proprietary oil-based fluid during the fabrication process. The four frames show the gradual inflow of the fluid from the right tube, making the channels appear to vanish.

05 A cylindrical device eight millimeters in diameter (right) controls fluid flows. It contains a fluid reservoir and an actuator that communicates with a smartphone or other device through a wired connection.

06 A laser is used to measure the height of the raised buttons. They can be custom-designed to rise 0.5 to 2.0 millimeters from the screen.

04



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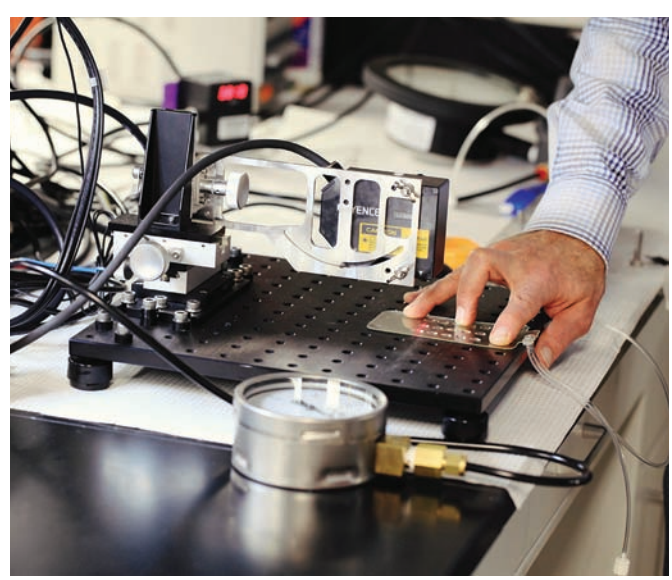

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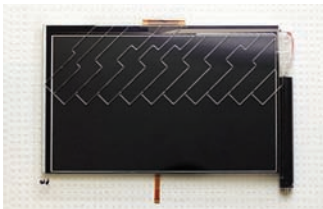

07

07 The fluid controller sits to the right of this unfilled Tactus panel, sized for a tablet computer.

08 In this demo, a panel replaces the glass top layer of an iPhone 3. The user must depress a button to type a number.

08

say, a person launching a text-messaging app, an actuator pumps additional fluid into the channels, and buttons rise up from an elastomeric cover. The user then depresses the button slightly to trigger the touch screen and enter the letter or number. When typing is done, the panel reverts to a flat screen for finger-swiping within one second.

Tactus isn't the only company recognizing a need for screens to offer tactile or so-called haptic feedback. Many phones already have rudimentary versions; tapping a certain button makes the whole phone buzz. Emerging designs include piezoelectric actuators that make the vibrations more localized. (Apple recently filed a patent on such technology.) And other companies, including Disney and a startup called Senseg, are using electrodes to issue minuscule shocks to your finger, simulating a rough texture.

Tactus's approach, however, is the only one that allows users to orient their finger on the screen before actually depressing the key, or to rest their fingers on buttons without triggering them. Tactus is working to improve the panel's appearance and create custom demonstrations for equipment manufacturers. One partner collaborating on prototypes is Touch Revolution, a division of the Taiwanese company TPK, one of the world's largest touch-screen manufacturers.

Button geometries can be customized during the manufacturing process. In a tablet or smartphone, software would probably change touch-sensitive areas of the display on the fly so that they'd align precisely with button shapes. This would prevent accidental keystrokes when fingers touch areas between raised buttons.

Tactus CEO and cofounder Craig Ciesla, who raised $6 million last year in venture investments, expects products to reach market in late 2013. "It's really a design tool to give to manufacturers," he says.

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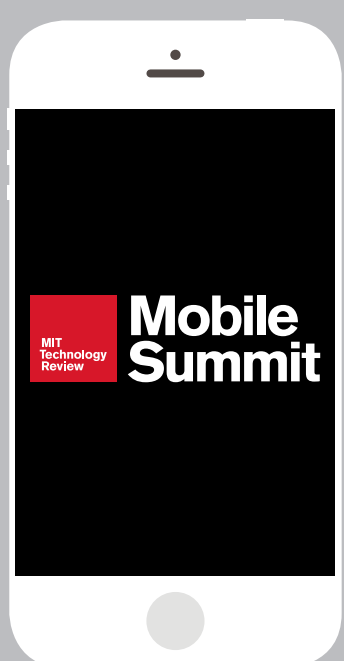

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100 Years Ago

The Nieuport monoplane is readied for flight, July 1910.

The Airplane's Infancy

By 1913 we'd learned how to fly. Now came the hard part—designing flying machines that were safe and reliable.

When the flying machine first publicly appeared in this country, back in 1908, it will be remembered what universal enthusiasm was aroused … Schools all over the country founded aero clubs and went to work building aeroplanes and gliders with a vim which did credit to their energy rather than to their understanding … The only reason why some of the aeroplane builders did not come to grief was because none of them succeeded in producing a machine which could get an appreciable distance above the ground.

To the rule of general hysteria, however, there was one notable exception. As long ago as 1896, at [MIT], through the work of Gaetano Lanza, ... a beginning was made in a direction where educational institutions could really be of service … His experiments were directed mainly to ascertain the lift and drift of surfaces at different angles in air-currents of varying speed. It is due to this experimentation that aviation and aeroplane construction has been raised from an art to a science. Formerly it was necessary for the builder to work by rule-of-thumb methods. He brought out his machine, not knowing whether or not it would fly, and altered here and there until he was able to get into the air. He was not certain, until he tried it, how much support a given curve of surface, driven at a given speed, would afford him. Only from actual flight could he estimate the varying head resistance of different sizes and arrangements of bracing, chassis, and out-rigging.

Today he either has the information already at hand, or can obtain it from an engineer. In fact, the development of the Nieuport monoplane, the first speed craft, was wholly scientific. Nieuport worked out his figures by laboratory experiment and applied the result to a full-sized machine, knowing just what to expect before it had left the ground. All of the European constructors have been forced to follow this method.

The lack of this exact knowledge in America has proved to be a great handicap, and already steps are being taken to remedy it. Last month President Taft, it will be recalled, named a commission to consider the establishment of a national laboratory for aerial research. All governments, however, move slowly, and none more so than that of the United States. It is imperative that steps be taken immediately to build a laboratory if America is to fall no further behind in the race for the supremacy of the air."

Excerpted from "Training Aeronautical Engineers," by Charles M. Chapin, in the July 1913 issue of The Technology Review.

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